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POTENTIAL POLLUTANTS IN FOSSIL FUELS

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E. M. Magee, H. J. Hall, and G. M. Varga, Jr.

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The report presents and analyzes data obtained from the literature on sulfur, nitrogen, and other potential pollutants in fossil fuels consumed in the United States. The data are categorized according to the location of the raw fuels, and are analyzed for geographic effects on composition. The trace element information available for coal is significantly greater than for oil; however, additional data are needed for both coal and oil on all potential pollutants in order to allow complete characterization of the pollution potential of a fuel.

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Oil shale
Contaminants
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Nitrogen
Trace elements
Ashes
Lignite
Crude oil
Manganese
Zirconium
Tin
Barium
Beryllium
Fluorine
Arsenic
Selenium
Cadmium
Mercury
Lead
Boron
Titanium
Vanadium
Chromium
Cobalt
Nickel
Copper
Zinc
Gallium
Germanium
Molybdenum
Lanthanum
Uranium
Lithium

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by

E.M. Magee, H.J. Hall, and G.M. Varga, Jr.

Esso Research and Engineering Co.
P.O. Box 8
Linden, New Jersey 07036

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Control Systems Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

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A. INTRODUCTION

The purpose of this survey is to present the composition of typical U.S. fossil fuels by source location, and the extent to which the selection of coals and crude oils by geographic source can be expected to affect their composition in trace elements. The first section deals with coals produced and consumed in the United States. The second section on petroleum and shale oil includes domestic crudes and crudes from nations which export to this country. Knowing the composition of fuels provides a background for the assessment of the probable fate of the trace elements present as potential pollutants, as affected by primary conversion treatments applied to the fossil fuel.

Almost half of the coal produced is consumed as mined, without preliminary processing. The same is not true for petroleum, which is burned in only limited quantities as total crude. In both cases any initial processing, by cleaning or by fractionation, usually produces a waste or bottoms fraction which is enriched in undesirable components, and this waste may create pollution problems when present methods of handling or disposal are used. These problems are known and fairly well defined for sulfur, but there is no comparable body of data for the pollution potentials of other elements.

The problems due to the ash from burning are completely different for oil and coal. Most oils produce much less than .1% of ash, most of which is emitted to the atmosphere. Coal produces some 3 to 20% of ash, commonly about 10%, but this ash adsorbs many volatile materials reducing their quantities in stack emissions. The major split is between fly ash and bottom ash, which is determined by equipment and operating conditions.

The number of elements for which statistical data on composition and geographical location exist is entirely different for crude oil and for coal. Good data and useful correlations with source locations are available for petroleum, for sulfur, nitrogen and nickel/vanadium, but not for other potential pollutants. A large body of data is available for trace elements in coal, and is examined herein. For both coal and petroleum, however, the level of trace elements present is relatively low so that methods of sample selection and sample handling, prior to analysis, can and do present major complications in the interpretation of results.

Nearly complete data are available for sulfur in coal; nitrogen is always relatively high; and comprehensive field reviews have been published on the other elements present. However, these data must be examined with caution before they can be used to indicate the distribution of trace elements in typical coals. Primarily this is because the samples were obtained for quite a different purpose, i.e. considering coal as a potential mineral resource. The selection of samples for this purpose started with a strong emphasis on mineral specimens of unusual composition, and shifted gradually over the years so that some areas of the country were covered on one basis and others on another. In the first studies of uranium in coal, for example, the typical coal containing less than 10 ppm of the element was dismissed as of no interest, and data were only reported for the atypical exceptions. In some later studies, a screening procedure was applied which selected for analysis those samples which gave the highest percentage of germanium on ash as being most promising for a desirably high content of other trace elements. An effort is made in this study to reduce the bias toward unusual specimens, and draw correlations based on adjusted data.

Finally, it should be noted that while literature on newer methods of analysis such as neutron activation is available, the "typical samples" used to calibrate these studies to date are mostly unidentified as to exact source. For both coal and oil, the contribution which these methods will undoubtedly make to trace metal analyses is still to be confirmed by further experience.

The authors wish to express thanks to the various people who have been kind enough to furnish information, advice and criticism during the course of this work. These very helpful people include Messrs. Peter Zubovic and Vernon E. Swanson of the U.S. Geological Survey, Hyman Schultz of the U.S. Bureau of Mines, P. D. LaFleur of the U.S. National Bureau of Standards, W. Fulkerson of the Oak Ridge National Laboratory, H. B. Charmbury of the College of Earth and Mineral Sciences of the Pennsylvania State University, J. M. Sugihara of the College of Chemistry and Physics of North Dakota State University, T. K. Janes and W. J. Rhodes of the U.S. Environmental Protection Agency, and M. H. Farmer, R. L. Mathiasen and R. A. Hofstader of Esso Research and Engineering Company.

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B. COAL

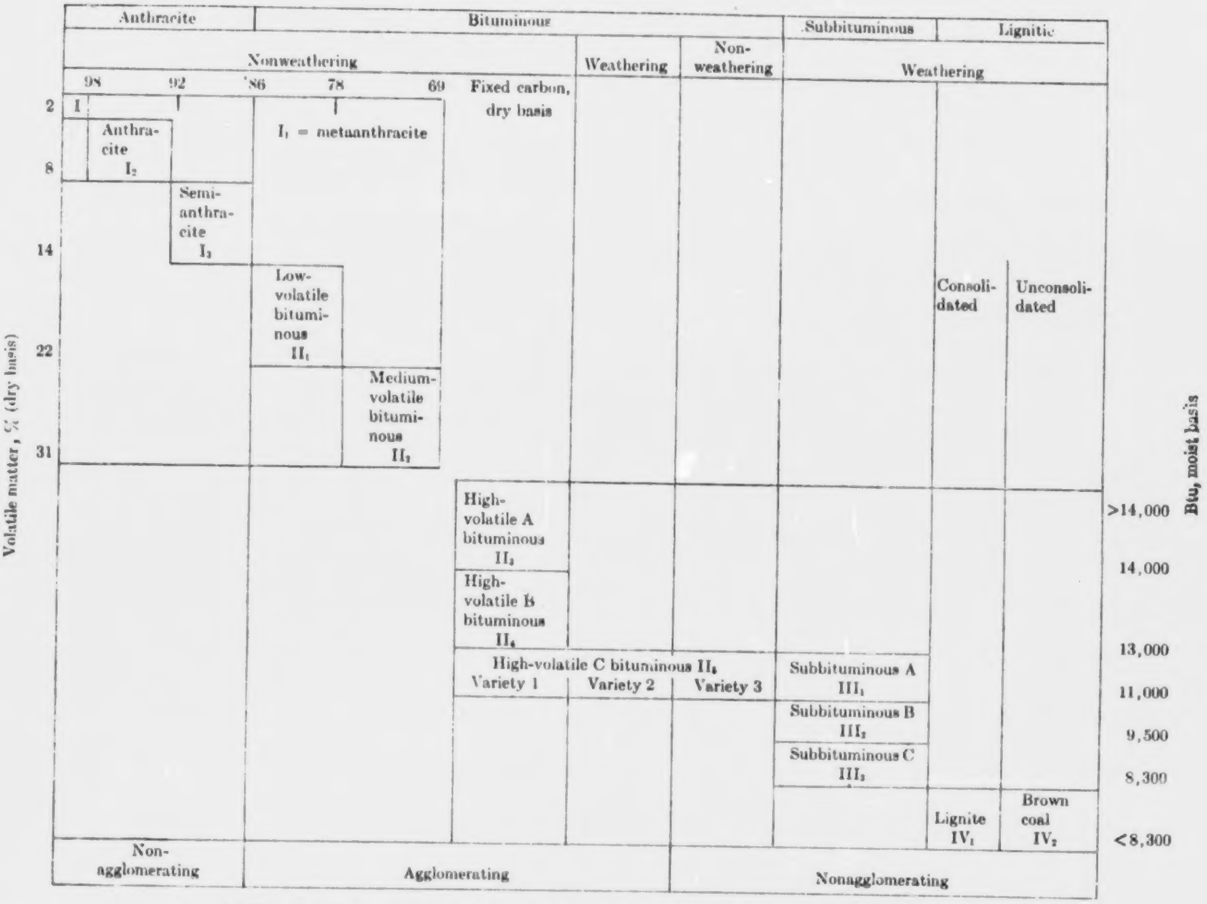
1. Background

1.1 Coal Types and Quality

The quality of coal and its effect on market value has been measured traditionally in terms of its use by the general public for domestic heating and small industries. For these uses anthracite coal, which is clean-burning, dust free and of moderate ash, has a considerable premium value. Coals are ranked systematically by volatile matter content and Btu per pound, from anthracite to bituminous to lignite and peat. A century or more of geological and mining research has shown that coal rank can be correlated with geological structure and geographical location, and used as a guide to locating and characterizing valuable new mines. These correlations are shown in the ASTM classification scheme commonly used in the United States, in Table 1.

Coal is primarily organic matter consisting essentially of C, H, O, N, and S. All of these are combustible except for oxygen, whose increase in amount correlates with a decrease in rank of the coal. The inorganic mineral matter present is associated partly with the coal but primarily with the ash, which ranges between 3% to 20% in commercial coals, averaging about 10% by weight. Ash content is to some extent an independent variable in coal quality. It reflects both care in mining and cleaning of the run-of-mine coal, and the intrinsic grade or quality of the coal itself. Coal by definition may contain up to 50% inorganic matter.

TABLE 1


Anthracite
Bituminous
Subbituminous
Lignitic
Nonweathering
Weathering
Non-weathering
Weathering
98
92
86
78
69
Fixed carbon, dry basis
2
8
14
22
31
Volatile matter, % (dry basis)
I
Anthracite I_2
I_1 = metaanthracite
Semi-anthracite I_3
Low-volatile bituminous II_1
Medium-volatile bituminous II_2
Consolidated
Unconsolidated
High-volatile A bituminous II_3
High-volatile B bituminous II_4
High-volatile C bituminous II_5
Variety 1
Variety 2
Variety 3
Subbituminous A III_1
Subbituminous B III_2
Subbituminous C III_3
Lignite IV_1
Brown coal IV_2
>14,000
14,000
13,000
11,000
9,500
8,300
<8,300
Btu, moist basis
Non-agglomerating
Agglomerating
Nonagglomerating

ASTM classification of coals by rank. Courtesy American Society for Testing and Materials.

The elements which make up most of the ash of coal are the common rock forming constituents: silicon, aluminum, calcium, iron and smaller amounts of magnesium, titanium, sodium and potassium. These are almost always present in coal. Their relative amounts may vary widely, depending in part upon the composition of the rocks adjacent to the coal. Typical ranges for the amounts of these oxides in the ash of coals of various ranks are given in Table II.

These elements which are major constituents of the soil and common rocks are not normally considered as pollutants; therefore, they are not discussed in detail in this report.

Questions of what coal types and elements are of special interest for pollution control are directly affected by changing patterns of use. The shift from domestic heating to electric power plant boilers as the principal areas of use and public concern for the environment has accelerated rapidly since World War II. The production of anthracite coal which was most valuable for home use peaked at 100 million tons a year in 1917. It has declined steadily from this level, except for a short spurt after World War II, to less than 10 million tons per year since 1970(1). The loss of this premium market has erased much of the older emphasis on differences due to coal rank, and values based on geographical location and accessibility have become correspondingly more important.

Bituminous coals are much more widely distributed than anthracite, but they tend to be of higher sulfur content, as well as less clean burning. It is well known that industrial and residential areas burning high sulfur coals have had serious problems with air pollution. Public

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(1) Superscript numbers refer to attached Bibliography.

TABLE 2

VARIATIONS IN COAL ASH COMPOSITION WITH RANK(1)

Rank	% SiO_2	% Al_2O_3	% Fe_2O_3	% TiO_2	% CaO	% MgO	% Na_2O	% K_2O	% SO_3
Anthracite	48-68	25-44	2-10	1.0- 2	0.2- 4	0.2- 1	-	-	0.1- 1
Bituminous	7-68	4-39	2-44	0.5- 4	0.7-36	0.1- 4	0.2- 3	0.2- 4	0.1-32
Subbituminous	17-58	4-35	3-19	0.6- 2	2.2-52	0.5- 8	-	-	3.0-16
Lignite	6-40	4-26	1-34	0.0-0.8	12.4-52	2.8-14	0.2-28	0.1-1.3	8.3-32

(1) From "Mineral Matter and Trace Elements in U.S. Coals," OCR R and D Report No. 61, Pennsylvania State University (1972), Table 13.

attention was focussed on this problem during the 1950's by two serious air pollution episodes in which a number of lives were lost due to the effects of acid smog, first in the Donora Valley near Pittsburgh in 1948 and second in a highly publicized one in 1952 in London. These were followed by a series of lesser episodes in many other areas which resulted in a strong emphasis on low-sulfur coals. This trend was reinforced in Pittsburgh, London and elsewhere by data demonstrating the seriously harmful effect of sulfurous and sulfuric acids on stone buildings. The combination of the decline in anthracite use, accompanied by a very large increase in public utility demand and growing concern with air pollution has led to a continuing decrease in sulfur tolerance in consumed bituminous coal, as well as in other fuels(2).

The availability of low sulfur coals was thoroughly explored during the 1960's. Definitive data are contained in a U.S. Bureau of Mines study as of 1966, with particular attention to the relationship between coal as a pollutant and the exact source of the coal(3).

1.2 Source Regions

Geological and geographical relationships have proved to be important guides to the location of specific regions and beds where the coal produced has a low ash or sulfur content. This information is used regularly in pollution control. One object of the present survey is to examine the extent to which such relationships do or do not exist for other trace elements.

These correlations are commonly presented in terms of the major coal-producing areas in the United States. They are grouped by state into six geographical provinces, as used by the U.S. Bureau of Mines (USBM)(4) and U.S. Geological Survey (USGS) and shown in Figure 1. The data collected in this review are presented primarily in terms of four of these provinces, as listed in Table III. These major areas are the Appalachian Province, the Interior Province, the Western Region which contains the Rocky Mountain Province plus Washington, and the Northern Great Plains Province. The other two provinces, Pacific and Gulf, produce only trivial amounts of coal.

TABLE 3
DISTRIBUTION OF COALS IN THE U.S.

Region	Abbreviation	States Included
Appalachian	A	Pennsylvania, Ohio, West Virginia, Maryland, Virginia, Eastern Kentucky, Tennessee, Alabama (and Georgia)
Interior-Eastern	IE	Illinois, Indiana, Western Kentucky, Michigan
Interior-Western	IW	Iowa, Missouri, Nebraska, Kansas, Oklahoma, Arkansas, Texas
Western	W	Wyoming, Idaho, Utah, Colorado, New Mexico, Arizona, and Washington
Southwestern	SW	Utah, Colorado, Arizona, New Mexico
Great Northern Plains	N	Montana, North Dakota, South Dakota

The numbers shown on each state in Figure 1 are the number of samples selected for spectrochemical analysis in a 1969 survey by USBM(4), as typical of current U.S. production. The larger numbers shown in circles are total production figures for each region during 1969, in thousand tons per day (3)

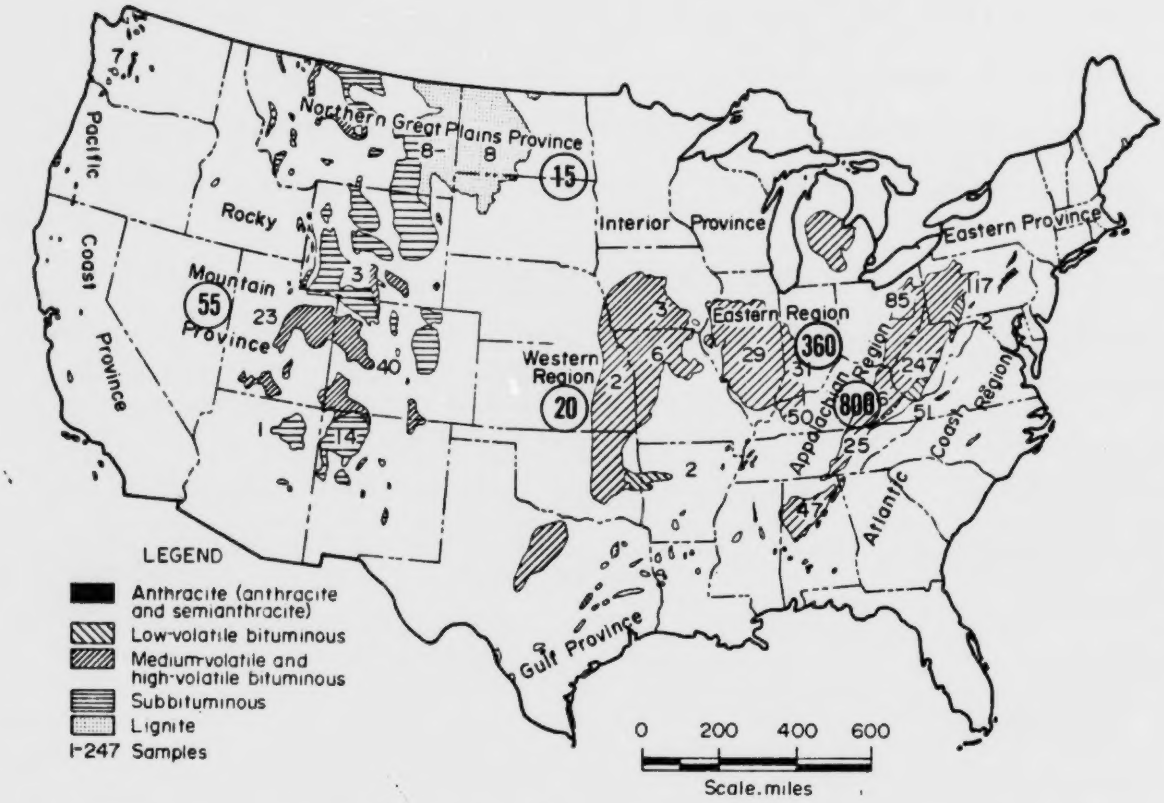
Pacific Coast Province
Rocky Mountain Province
Northern Great Plains Province
Interior Province
Eastern Province
Western Region
Eastern Region
Appalachian Region
Atlantic Coast Region
Gulf Province
7
8
8
15
3
55
23
40
1
14
3
6
2
20
2
29
360
31
50
800
25
85
117
2
247
51
47
LEGEND
Anthracite (anthracite and semianthracite)
Low-volatile bituminous
Medium-volatile and high-volatile bituminous
Subbituminous
Lignite
1-247 Samples
0 200 400 600
Scale.miles

FIGURE 1. - Map Showing Number of Samples From Each State. (From Ref. 4)

The Appalachian region contains most of the anthracite coal in the United States, and the largest and most important continuous bituminous deposit in the world. These coal beds and the Pennsylvania rock strata in which they occur are intensely folded along their southeastern outcrops. The rank of the coal tends to increase in this direction, with intensity of folding, thickening of formations, and depth of burial.

The Eastern Interior region coincides generally with the outline of the Illinois basin, where the coal-bearing Pennsylvania strata extend across most of Illinois, southwestern Indiana, and western Kentucky. The coals in this region are largely high-volatile bituminous. The Interior Western region contains large deposits of medium-to-high volatile bituminous, which have not been extensively mined because they are too far from the eastern centers of population and industry. These extend across Iowa, Missouri, eastern Nebraska and Kansas, into Oklahoma, with a related bed in Texas. A smaller area of low volatile bituminous and anthracite extends over into Arkansas.

The small lignite beds in Texas and Arkansas extend over into Alabama, and are properly in the Gulf Province. They are of only fair quality, and few analyses for them are available. These have been included with the Interior Western region in the USBM studies, for convenience.

Coals in the Northern Great Plains province comprise enormous deposits of lignite and sub-bituminous, which have scarcely been touched. Lignite is characterized by a high content of water and ash, and an ash content of alkaline earths which is significantly higher than other coals.

The Western region is defined here, as in the USBM studies of coals by regions, to include the Rocky Mountain states and a few isolated samples from the Pacific northwest. A Southwest sub-region at the 4-Corners area of Arizona, New Mexico, Utah and Colorado has been studied extensively in a recent comprehensive review by the Southwest Energy Study group. Data from this report are considered reliable to a lower concentration level than earlier analysis in several cases, such as cadmium and selenium, and they are identified separately (as SW) where used.

The Appalachian and Interior-Eastern regions have had a major effect in the development of the U.S. economy. These regions are well documented by many analyses. These and the Interior Western region comprise 80% of the U.S. reserves of both bituminous and anthracite deposits, most of which must be worked by underground mining. Essentially all of the lignite and sub-bituminous deposits are located in the Northern and Western regions. Much of these is found in beds which can be strip or open-pit mined at very low unit costs. This has led to the development of large new power plant installations at some distance from the point of demand, as at the 4-Corners area which now supplies electricity to Southern California.

In the eastern bituminous and anthracite areas, the coal minerals are owned privately and their exploitation is largely controlled by economic factors, chief of which are proximity to market and coal quality. The majority of the lignite and sub-bituminous reserves of the western states are associated with public lands, administered by federal and state agencies. These coals are further from today's markets, and are generally of lower quality.

1.3 Potential Pollutants

Public concern over minor or trace elements in coal as a potential source of air pollution was limited almost entirely to sulfur until recent years, after about 1967. The initial concern and the first official actions were directed to smoke control, to limit the production of soot, fly ash, and odorous organic materials. While these problems may reflect coal quality in terms of rank, or content of volatile tars, they can be controlled by careful adjustment of combustion conditions. The production of fly ash or cinders is tied to total ash content and composition, but it is scarcely affected by which trace elements are present in the ash.

The pollutant element other than soot which has been and still is of most concern is sulfur, which is converted quantitatively on combustion to acid sulfur oxides. The sulfur in coal is present both in the organic and in inorganic portions. The organic portion is primarily ring sulfur compounds, thiophene and benzothiophene derivatives, which are the principal S compounds in low sulfur coals. Most of the inorganic sulfur is in the form of iron disulfide, pyrites or its polymorph marcasite. A much smaller amount appears ordinarily as sulfate sulfur such as gypsum. This appears (or is formed in the ashing process) as the major sulfur compound in lignite ash.

The nitrogen compounds in coal are again almost exclusively organic. There are significant amounts of both pyrroles and pyridines, 5- and 6-membered rings, and their higher homologues. The porphyrin systems of N-ring chelates play a role in the trace elements present. They act directly to introduce organic iron and magnesium derived from original plant chlorophyll, and indirectly through the substitution of other elements for these during geologic metamorphoses. The presence of inorganic nitrogen in lignites is again a special case, since as much as 1% by weight can be extracted from some lignites as water soluble sodium and alkaline earth nitrates.

The interest in other elements in coal up to about 1967 was almost entirely on its use as a possible mineral resource. This was explored during the 50's and 60's in comprehensive reviews for a few elements such as uranium, beryllium, germanium and gallium in the U.S., and for mercury in the USSR. Concentrations of interest from this point of view cut off at about 10 ppm on ash or 1 ppm on coal, and few of the older analyses go below this level(4).

Trace elements are usually defined as those present in the earth's crust to the extent of 0.1% (1000 ppm) or less. Nearly all trace elements show an enrichment in coal ash relative to their crustal abundance. The USGS data on coal ash are summarized on this basis in Figure 2. This enrichment is attributed to concentration effects during growth of the coal-forming plant (syngenetic processes) or by exchange reactions with the surroundings during coalification (epigenetic processes). Boron which is picked up by plants from the underlying soil is enriched even on the total coal basis (syngenetic), and germanium is equally enriched in some coals (epigenetic).

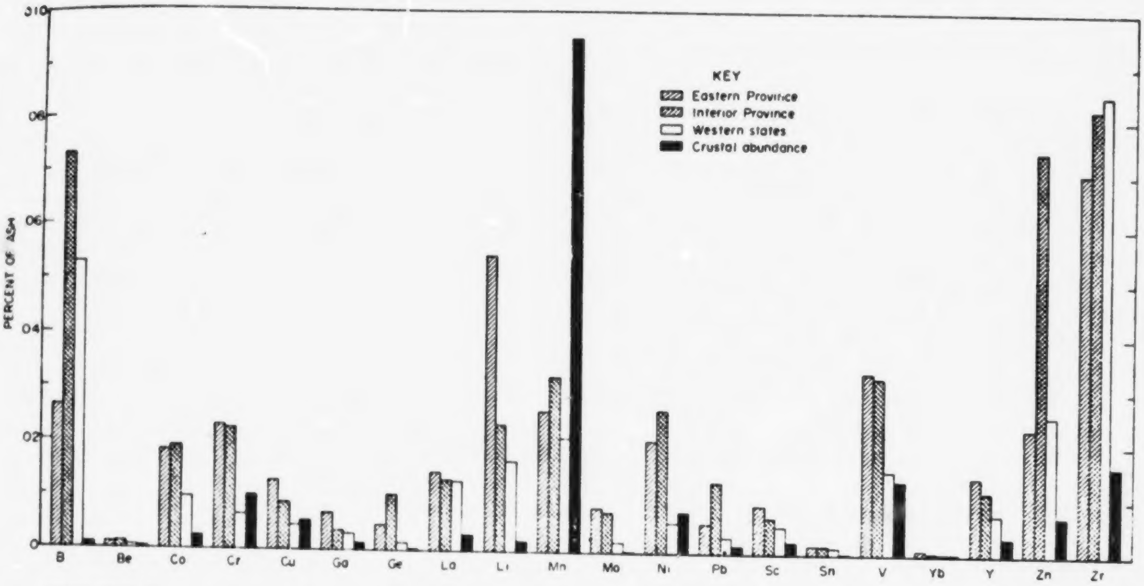

FIGURE 2. - Average Trace Element Content in Ash of Coal From Three Areas Compared With Crustal Abundance (4).

Anthracite coals tend to have a low ash, but coal rank, in general, is not a decisive factor in the relative amounts of different trace elements present. The coals of lowest rank, lignite and peat, show high ash with a very high content of calcium, sometimes of sodium, and of barium and strontium which tend to go along with calcium. Boron is also high in lignites, but the lignite ash, by reason of its high content of alkali and alkaline earths, is proportionately low in its content of other trace elements (simple dilution effect).

High concentrations of specific trace elements may be closely associated with the presence of ore beds nearby. This is true for coals of any rank. Ash samples showing significant concentrations of such metals as mercury, lead, uranium, copper, zinc and tin are used to indicate the possible location of workable mineral deposits. Samples which show unusual concentrations of these elements are selected regularly for special interest as mineral specimens. This bias toward specimens of mineral interest must be discounted heavily in some cases, since they can receive much more than their proper weight in correlations based on a limited number of samples.*

A list of minor elements present and the trace elements on which sufficient data are available for review in this report is given in Table IV. The trace elements are considered in three categories and arranged within each in the order of increasing atomic weight.

---

*An example is the 1971 article by Joensuu on the high mercury content of U.S. coals, in which 11 of the 36 specimens analyzed contained over 1 ppm of Hg on coal, but 8 of the 11 were multiple samples from the same 3 counties(5).

TABLE 4

Minor and Trace Elements in Coal

Minor Elements
(about 1% or more, on ash)

Pollutant
- Sulfur
- Nitrogen

Ash-forming
- Sodium
- Potassium
- Iron
- Calcium
- Magnesium
- Silica
- Alumina
- Titania

Trace Elements
(about 0.1% or less, on ash)

Named as Hazardous
- Beryllium
- Fluorine
- Arsenic
- Selenium
- Cadmium
- Mercury
- Lead

Others Analyzed

Coal Basis
- Boron
- Vanadium
- Chromium
- Cobalt
- Nickel
- Copper
- Zinc
- Gallium
- Germanium
- Tin
- Yttrium
- Lanthanum
- Uranium

Ash Basis
- Lithium
- Scandium
- Manganese
- Strontium
- Zirconium
- Barium
- Ytterbium
- Bismuth

The first category includes seven trace elements named by EPA or commonly elsewhere in the literature as hazardous to human health. It is undoubtedly no coincidence that these toxic elements are all volatile or can appear in stack emissions as volatile stable compounds. The definition of hazardous elements must be carefully considered, however, since many elements are essential to metabolism in trace amounts. Selenium, for example, is as hazardous to health when it is completely absent as when it is present in slight excess. Similar observations apply to Cu, Mo, Co, I and other elements. Again, it is no accident that the level of metabolic tolerance in many cases is close to average crustal abundance, the amount of the element found in ordinary dirt.

The second category includes other elements which have been analyzed in extensive field reviews, and reported on a coal basis in the literature. These are the elements selected by USGS as most significant for its studies of the chemistry and geology of coals, as determined by a standard procedure for emission spectroscopy. Titanium, included in the USGS studies, is an ash-forming element present regularly in amounts greater than 0.1%. It is not considered as a trace element for the purposes of the present review. Yttrium is listed next to lanthanum for convenience in intercomparisons.

The third category includes elements for which data are available only on an ash basis, from USBM studies of commercial coals.

1.4 Fate of Elements on Combustion

The sulfur in coal (or otherfuels) goes quantitatively to SO_2 on combustion. A small but variable portion of this is oxidized further to SO_3. This goes in turn to form acid mists on combination with moisture, or sulfate in ash on combination with alkali or alkaline earths. The amount of sulfate formed depends primarily on the amount of lime or other alkaline earths present in the combustion zone. Lignite ash is intrinsically high in lime, derived presumably from calcium humates in the coal, and the ash is high in retained sulfate. This reaction can be increased by the addition of free lime or limestone to the combustion zone as a means of pollution control, to decrease the stack emission of sulfur oxides. The lime fixes gaseous SO_2 as well as SO_3, and the calcium sulfite formed can be regenerated or oxidized further by air to the sulfate.

The fate of various trace elements also depends to some extent on other constituents present in the ash. This is particularly true for vanadium which may react with alkali, under reducing conditions, to form a vanadate slag. This can be seriously corrosive to boiler tubes or heat exchange equipment, such as a gas turbine, but this is a high temperature situation, and it is not considered as a pollution hazard. Acid corrosion due to the presence of chlorides from coal ash in the combustion zone is also a high temperature reaction, which is quenched at lower temperatures and not considered as a pollution hazard. Fluorides are released to some extent in fly ash, and emitted as such.

Other trace elements are converted primarily to the oxides, and split between fly ash and bottom ash depending on their chemical and physical properties. Germanium and gallium are both enriched in fly ash enough to represent a significant mineral resource. A few of the heavy metals are so electropositive that they appear as the free element. This applies chiefly to mercury, although occurrences of free silver or gold have both been noted in the ash of coals from mines adjacent to rich ore beds.

The fate of nitrogen in fuel depends to a major extent on the conditions of combustion, and the presence of a high nitrogen content in coal does not correlate directly with the amount of nitrogen oxides produced. The nitrogen compounds formed or released during partial vaporization in the combustion zone prior to burning may either oxidize, depending on conditions, or combine with nitrogen oxides in the combustion gases to produce free nitrogen. The total production of NO_x is affected to a major extent by the maximum flame temperature and the presence of excess oxygen, and it can be reduced even for high N-containing fuels by controlling these variables. The amount of nitrogen in all coals is within the range of about 1-2% by weight, with distribution curves peaking between 1.1 and 1.5%. These values are all high compared to other fossil fuels. They have a large effect on NO_x production, but the difference between one coal and another is too small to have much of an effect. The differential effect between coals is trivial at best compared to the order of magnitude difference between SO_x emissions from coals of high and low S content. On this basis, the distribution of N in coals is not considered as a primary variable for air pollution controls.

The only fossil fuels regularly sold now for their low pollution characteristics are low sulfur oil and coal, and oils of low nickel/vanadium content for use in gas turbine and boilers. While coals of high V/Ni content can be found, e.g., in Kentucky, they are not common. The increasing interest in specific hazardous elements, such as mercury, will undoubtedly direct more attention to avoiding fuels in which their concentration is unusually high.

2. State of the Art

2.1 Evaluation of Data

Continuing field surveys of U.S. coals have been made by three major government laboratories, using the best methods available to them. These surveys are made for three different purposes, and they differ more in the method of sampling than in the procedures for analysis. The rest of the literature on trace elements in coal is concerned almost entirely with new methods of analysis, tested or intercompared on a single sample or a few known samples. Except for missing data on single elements, these have relatively little to contribute to an overall review. The three basic sets of data and samples are:

Surveys of commercial coals - USBM (delivered samples)
Mineral source surveys - USGS (column samples)
Specific element studies - AEC (USGS, Oak Ridge; specimens)

The USGS data are found to come closest to the purposes of the present program: to determine the composition of typical U.S. coals by regions and the extent to which the selection of coals by geographic location can be expected to affect their composition in trace elements.

The analyses made in these field surveys did not regularly include data on mercury, cadmium, arsenic, selenium, or fluorine. These are all on the list of seven hazardous elements, and they constitute the entire list except for beryllium and lead. They are volatile elements not readily detected by emission spectroscopy, and better methods for their analysis were required.

Recent studies which have helped supply missing data have been completed by the Illinois State Geological service, particularly for mercury(6). Improved results on fluorine have been obtained by USBM(7), and by USGS as part of the Southwest Energy Study(8). The National Bureau of Standards is also taking an active part in the preparation and analysis of standard samples for an industry-wide program of collaborative testing of new methods of analysis including Pb, Cd and As, coordinated by the Bureau of Mines(9). The reuse of older samples for ties to new data is suspect, however, and a broad field review must start with new samples of coal. One of the problems in previous analyses has been the loss of the volatile elements on ashing. In other cases they may also be picked up from the environment. This is the apparent explanation for high mercury values in Headlee and Hunter's analyses of West Virginia coals exposed to laboratory air(11). Similarly, the USBM laboratory in urban Pittsburgh has found that its background level of lead and mercury on lab equipment is higher than that in coal samples being analyzed, and the problem increases with time of exposure(10).

The effect of different analytical procedures in the laboratory is often minor compared to the effects of sample selection and preparation in the field. Major variables are involved. The samples selected may represent coal as delivered, cleaned or uncleaned, or coal in the mine, which can be either a complete column cut from the full height of the bed or blocks within such a column selected for study because they appear to be different. All of these methods are used, and all of them can be considered as "correct" as long as they are recognized for what they are. All of them appear in the literature together, however, and frequently intermixed in the same article. No distinction is made in many studies whose primary purpose is the development of a new method of analysis. The result is that most of the miscellaneous analyses in the literature cannot be combined properly into a single compendium.

The most important and most confusing factor in the interpretation of the data in the literature is the basis of selection of the original sample. Coals selected for their interest as mineral specimens are exactly the ones to avoid for purposes of pollution control, if the specific element concerned is found to constitute a potential hazard. These analyses exist in the literature precisely because they are unusual and not representative of the average run of mine. The same conclusion applies whether the mineral resource sampling refers to selected blocks in a partially analyzed column, or selected mines in a given region.

2.2 Methods of Correlation

Efforts to draw useful correlations between the location of coals and their content of specific trace elements have been hampered by the tendency to use averaged data, and the fact that the basis of sampling for analysis has shifted during the course of major field surveys. The problem is particularly serious when samples are intermixed in the same program which are "of interest" for opposite reasons: because they are typical on the one hand, or because they are unusual on the other. The analyst in this case finds no basis to discard a high result which he finds analytically correct, even though it greatly affects his average. This problem was recognized by Zubovic, for example, in the analyses reported for zinc in Illinois and elsewhere(12). In such a case, the modal value for the average coal may be quite different from the average reported on all good data. This can be significant for pollution controls, since the expected analysis for delivered coals might be reduced to the mode by excluding a few samples which are easy to identify.

The fact that such extremes do or do not exist and the producing areas in which they are found may be of definite interest in considering these trace elements as potential pollutants. The unusual data should somehow be put into perspective, and not simply discarded.

The literature was reviewed with these problems in mind. Three concepts are proposed as working tools to make the most out of the present data, with a minimum of recalculations:

(1) A "variance" ratio is given for each element, which is the ratio of the highest to lowest average of analyses for areas or basins within the region. This variance is a measure of the extent to which selection of coal source can be expected to make a difference in the concentration of a given element. It is applied here to groups of about 3 states but can be used for smaller areas, for simple geographical correlations such as those which are now well known for sulfur. This variance is low for most elements, of the order of 2 to 3. It is 8 for sulfur and 4 or above only for Ge, B, Be, Ga, Zn, Sn and Mo, out of the 18 elements for which sufficient data are available to report.

The averages for areas within the region are given as reported by Zubovic. He divides the Appalachian region into 3 areas, considers the Interior Eastern as 1, the Interior Western as 2, and the Northern Plains as 1.

(2) Ranges for the USGS analysis of the coal beds within each region are selected which include 90+% of the values reported, for columnar samples, up to a cut-off point above which higher values appear to be exceptional. A columnar sample is defined as one for which at least 75% of the total depth of the coal bed was included in the sample analyzed. This makes a significant difference in some cases, particularly in sections A and B of the four-part USGS survey. At that time, the highest values reported were frequently not samples of the average coal but blocks selected as mineral specimens or lithotypes within the column. The 90+% range is taken from the data for beds within the region, after casting out these non-representative values. The next step was inspection to find an envelope within which most or all of the individual analyses represent a continuous distribution of values. The highest values reported were then considered individually, first to see that they represent a columnar sample at least 75% analyzed, and then as to the interval between this value and all lower values within the envelope. This inspection characterized many instances where a few columnar samples, up to about 5%, had extreme values 50 to 100% or more above the rest of the envelope. The cut-off point for these extremes was an interval of 25% or more above the highest bed value within the envelope. The significance of the extremes can then be examined separately, both in terms of their frequency and their magnitude as compared to average values or the top of the 90+% range. Detailed data on this are shown in Table XI, below.

(3) Ranges of data on the ash basis can be conveniently derived, for the same producing regions, from the averages by states given by Abernethy in USBM reports(4). These have been rounded off to three significant figures, partly for convenience for comparison with the data given by USGS and others on a coal basis. Thousandths of a percent on ash correspond exactly to ppm on coal, if the coal contains 10% of ash. This is a reasonable average approximation and it fills in many holes in the data, particularly for the Western region, without a laborious recalculation which would still not give directly comparable results.

When the elements are listed in the order of variance and magnitude of extremes, several useful correlations appear. This is shown in Table V. The elements with high variance and extremes which are no more than twice the top of the 90+% range are sulfur, germanium, boron, beryllium and gallium. Except for sulfur, which is both strongly organic and inorganic, these are all at the top of Zubovic's list of organic affinity. This means that on coal cleaning they tend to be associated with the coal fraction, and not the waste. They are also elements in which coal is greatly enriched, to the extent that it is recognized for most of them as a major mineral source.

The other elements which show a variance above 4 are zinc, molybdenum, and tin. For these the extremes reported are from 5 to 20 times the top of the 90+% range. Zinc and tin are at the bottom of the organic affinity list, and for them the occurrence of coals of high metal content is taken as a direct indication of ore beds

TABLE 5

VARIANCES AND EXTREMES IN AREAS[1]

Element	Variance[2] between Areas	Organic[3] Affinity	Extreme[4] Ratio
Sulfur	8		
Germanium	>10	1	2
Boron	6	3	2
Beryllium	5	2	2
Gallium	4	3	2
Molybdenum	4	6	5
Tin	>(3)	8	5
Zinc	>5	10	20
Lead	3		>10
Mercury	3		>10
Vanadium	2	3	3
Nickel	3	4	2
Chromium	2	4	2 (3)[5]
Cobalt	2	5	2 (5)
Yttrium	3	5	2 (10)
Copper	2	7	2 (3)
Lanthanum	3	9	2 (10)

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(1) From USGS Bulletin 1117, except for S, Pb and Hg.

(2) Approximate ratio between averages for highest and lowest areas, as published (see Table XI).

(3) Numbers assigned to USGS order of affinity:

Ga>Be>(Ga, B, V)>(Ni, Cr)>(Co, Y)>Cu>Sn>La>Zn

(4) Approximate ratio between extreme bed and top of range of 90+% envelope, for columnar beds analyzed.

(5) Discounted extremes in parentheses show exaggerated effect of two weathered coals from Arkansas with 41.7% and 47.3% ash, not included in area averages.

nearby. The variance of (3) reported for tin is placed in parenthesis because it represents a recalculation of the USGS data for one area in the Appalachian region. This is given a false low average of 0.1 in the original report by including a value of zero for 15 of the 17 samples analyzed for the region, in which the element was not detected. The USBM data in this area indicate no such differences between the tin content of coals in this area and other parts of the region, so this value was ignored in calculating the variance.

Molybdenum is another case where variance might be misleading. Here the average for the southern Appalachian area, Alabama, is raised from 3.9 to 5.8 by a single extreme value of 42 for one bed out of the 20 included. Without this one extreme, the variance reported would be under 3. The value appears valid but marginal (74% of the columnar bed analyzed). The fact that the value is so high may correlate directly with the AEC observation that Mo is the only element in coal for which they could correlate its high occurrence with a high occurrence of uranium.

Mercury and lead, for which no data are reported in the USGS field survey, have a variance of about 2 to 3 from other data. The ratio of extremes to average values for these two elements can be given any high value desired, up to 50-100, depending on how close one chooses to come to an ore bed in selecting the coal.

None of the remaining elements which show a variance of 3 or less has a ratio of extremes to the top of the 90+% range higher than 2, except vanadium at 3. This vanadium ratio directs attention to one mine in Kentucky which has a high Ni and V content. Other variances would be higher if it were not for discounting from the extremes two samples of Arkansas coals excluded in the USBM averages, which had ash contents of 41.7 and 47.3 weight %. The ratios of extremes on including these atypical samples are shown in parenthesis in Table V.

2.3 Literature Sources and Procedure

The collection and evaluation of information for this review have been guided wherever possible by expert opinion on the location and selection of useful source material. The first step was to collect and combine pertinent references already assembled in previous searches. Topics included were data and methods of analysis for specific trace elements in fuels, the effect of sulfur content or other pollutant elements on the availability of alternate fuels as a source of energy, and the fate of potential pollutants on combustion. These references provided an immediate preliminary overview of the field.

Additional searching first covered Analytical Abstracts from 1965 to July, 1972. This proved to be concerned primarily with more rapid or convenient methods, tested on known samples of previously analyzed coals, which added little to the data previously available. Significant contributions appeared in this period for a few elements, such as mercury, arsenic, and fluorine. A more useful source was the U.S. Bureau of Mines index of publications, from 1960 to May, 1972, including bibliographies of earlier reports. Key references from these searches were selected by abstract or index entries, and ordered in full for further study.

The next step was a search of the Engineering Arts Index from 1960 to July 1972, and a computer index search of the American Petroleum Institute abstracts of air and water conservation literature since 1967. At this point in the search, each additional index covered was giving an increasing amount of duplication of references already at hand.

The advice of EPA on preferred sources of information was obtained in conferences with the Project Officer and his associates. This was backed up by visits and telephone conversations with Peter Zubovic at the U.S. Geological Survey, Hyman Schultz at the U.S. Bureau of Mines (Pittsburgh) and Vernon Swanson at the USGS (Denver) to look for significant additional references. As a final check, a list of Chemical Abstracts entries for each element and general heading of interest for trace elements in coal was assembled, and used as a check list for topics where little or no data had turned up from other sources. Approximately 1200 references were considered in all.

2.4 Types of Analysis Found

The original wet chemical analyses of coal made each measurement of trace elements a research project, and relatively few determinations were made. A comprehensive survey of the data available as of 1935 was made by Goldschmidt (see Appendix I, Table 1)(13). The first standard method developed for analysis by emission spectroscopy was convenient for the simultaneous determination of a number of minor elements, but it cut off for most of them at about 10 to 50 ppm (that is, .001 to .005% on ash). This was proposed by Hunter and Headlee(11) and applied by them in 1955 to the analysis of 28 elements in the ash of West Virginia coals. Their list of elements and sensitivities reported is given in Table VI.

The U.S. Bureau of Mines has regularly collected and analyzed samples of coal from most producing areas in individual countries and mines throughout the United States, for 60 years. The samples are either cleaned or uncleaned coal from the mine tipple, analyzed as a basis of quality guarantees by the producer for purchase by government agencies. The USBM basic routine reports only ultimate analysis for % C, H, O, N, S, ash, volatiles, and physical properties, but the same samples have frequently been used as a source of representative coals, from different areas(14)

The U.S. Geological Survey has been more interested in the coal in place than in coal as delivered after sorting and cleaning. Spectrographic procedures developed at USGS in 1953 by Zubovic, Stadnichenko and others for the analysis of germanium in coal(15) were extended to the analysis of other trace elements, including sample dilution with a standard synthetic base material for more reproducible results. This method was used in 1961-67 for a definitive 4-part study of "Minor Elements in Coals" for each of the four major producing regions in the United States. This is the basis for the study of variance and extremes presented in Table V, above. Zubovic reports his results and averages on a coal basis, as well as his original data on ash. The limits of detection for most of elements considered are between

TABLE 6

WEST VIRGINIA GEOLOGICAL SURVEY - 1955

Table 54—Wave Lengths of Element Lines Employed for Analysis at the Concentrations Encountered

Element	Å	% Concen.	Å	% Concen.	Å	% Concen.
Li	6707.	<.005-1.00	....	......	....	......
Na	5895.	.3-1.3	3302.3	1.3-10.0	....	......
K	7698.	.4-4.0	....	......	....	......
Rb	7800.	<.03-.1	....	......	....	......
Ca	3158.	.1-4.00	2997.	4.0-20.0	2721.	20.0-35.0
Sr	4607.	<.01-1.0	....	......	....	......
Ba	4934.	.05-1.00	2335.	1.0-5.0	....	......
Mg	2783.	.1-2.0	....	......	....	......
Al	3050.	15.0-50.0	2652.	5.0-15.0	....	......
Si	2568.	40.0-80.0	2532.	20.0-40.0	2987.	3.00-20.0
Fe	3040.	1.0-10.0	2990.	10.0-40.0	2991.	40.0-80.0
Ti	3072.	.2-2.0	2646.	2.0-6.0	....	......
Ag	3230.	<.0005-.02	....	......	....	......
As	2780.	<.07-.3	....	......	....	......
B	2496.	.02-6	....	......	....	......
Be	3131.	.01-.10	2348.	<.0005-.01	....	......
Bi	3067.	<.004-.01	....	......	....	......
Cb	3163.	<.007-.05	....	......	....	......
Co	3044.	<.005-.10	....	......	....	......
Cr	2677.	.01-.05	....	......	....	......
Cu	3274.	.006-.10	2824.	.10-.50	....	......
Ga	2943.	<.005-.10	....	......	....	......
Ce	2651.1	<.005-.1	2691.	.1-.25	....	......
Hg	2536.	<.008-.06	....	......	....	......
La	3245.	<.035-.10	....	......	....	......
Mn	2801.	.004-.1	2933.	.1-1.00	....	......
Mo	3170.	<.006-.15	....	......	3194.*	<.001-.15
Ni	3050.	.006-.10	3101.8	.10-.50	....	......
P	2554.	<.2-8.0	....	......	....	......
Pb	2833.	<.015-.05	....	......	2663.	.05-.20
Sb	2598.	<.005-.03	....	......	....	......
Sn	2839.	<.01-.2	....	......	....	......
V	3102.	.01-.15	....	......	....	......
W	2946.	<.01-.05	....	......	....	......
Zn	3345.	<.05-.24	....	......	....	......
Zr	3279.	.009-.09	....	......	....	......

*Note—Used when sample contained Fe in excess of 15.0%.

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.0001 and .001 on ash, as shown in Table VII. There are 3 elements which show higher limits: the relatively high limit of .005 on Ti is of no concern, since this is always present in more than trace amounts. The same .005 level for Cd is critical, however, since the amount present is almost always below this level. This means there are almost no data available on the geographical distribution of Cd in coal, but whatever there is is well into the trace level of concentration. The high limit of .02 for Zn introduces a definite uncertainty into these analyses.

A comprehensive review of the literature on "Rare Elements in Coal" was assembled by Abernethy and Gibson at USBM in 1963(13) including the initial results reported by Zubovic. Data and conclusions are assembled from U.S. and foreign sources for each of 34 elements, regarding their occurrence in coal. Excerpts from this report, including the comments on specific elements, are attached hereto as Appendix I.

Abernethy, Peterson and Gibson at USGS in 1969(3) reported on the spectrochemical analysis of the ash from 827 U.S. commercial coals for 22 trace elements, plus 7 other elements detected in many samples. Their procedure involved a lithium borate fusion of the ash for more rapid analysis, as described by Peterson and Zink in 1964(16). This report presents data on the analysis of trace elements in the ash of coals from most producing states, countries and beds, and averages by state on the basis of ash. The full report is attached hereto as Appendix II. Current modifications of this procedure in a 6-step spectroscopic analysis as used by USGS have given further improvements in the limits of detection, as shown in Table VIII.

TABLE 7

USBM - 1961

METHOD OF SPECTROGRAPHIC ANALYSIS

EQUIPMENT AND LIMITS OF DETECTION

The analyses of the ash samples were made by a quantitative spectrographic method. The apparatus and operating conditions for the analyses are as follows:

Spectrograph:	A grating spectrograph, Wadsworth mounting, with a dispersion of 5 A per mm in the first order.
Electrodes:	A high purity carbon rod of 6 mm diameter, having a machined cup at one end, is used as the sample electrode (anode). The cup has a 4 mm inner diameter with a wall 0.5 mm thick and a crater 6 mm deep. The counter electrode (cathode) is a graphite rod 3 mm in diameter.
Excitation:	A 250-volt ballasted d-c arc, operated at 16 amperes, the analytical gap being maintained at 3 mm throughout excitation.
Exposure:	Samples and standards arced to completion.
Emulsion:	Eastman III-O, developed in DK-50 at 20°C for 5 minutes with continuous agitation.
Wavelength region:	2300 A—4700 A, recorded on two 10-inch plates simultaneously.
Microphotometer:	Projection comparator microphotometer, using a scanning slit at the plate.
Emulsion calibration:	Method of Dicke and Crosswhite (1943), using a two-step filter at the slit.

Analysis lines with limits of detection are tabulated as follows:

Table of analysis lines and detection limits for minor elements

Element	Wavelength (angstrom units)	Limit of detection (weight percent of ash)	Element	Wavelength (angstrom units)	Limit of detection (weight percent of ash)
B	2497.733	0.001	La	4333.734 3337.488	0.003 .01
Be	2348.610 3131.072	.0001 .001	Mo	3170.346	.0005
Cd	3261.057	.005	Ni	3414.765 3050.819	.0005 .001
Co	3453.505 3449.170 3449.411	.0005 .001 .002	Sn	3175.019	.002
Cr	4254.346 3021.558 3024.350	.0001 .001 .005	Ti	3261.605 3152.251	.005 .05
Cu	3273.962 2824.369	.0001 .05	V	3185.396 3183.406	.001 .001
Ga	2943.637	.001	Y	4374.935 3327.875	.001 .002
Ge	2651.178 3039.064	.001 .002	Zn	3345.020	.02

TABLE 8

Table 6 -- Approximate visual lower limits of determination for the elements analysed by the 6-step Spectrographic Method at the Denver Laboratory, U.S Geological Survey

FOR THE SOUTHWEST ENERGY STUDY, 1971

NOTE: Some combinations of elements affect the limits of determination. Approximate values are given. In unusually favorable materials, concentrations somewhat lower than the values given may be detected. In unfavorable materials the given limits of determination may not be attained for some of the elements.

Si, Al, Fe, Mg, Ca, Na, K, Ti, and P are reported in %; all others in ppm. Results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., but are reported arbitrarily as mid points of these brackets, 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of a reported value is approximately plus or minus one bracket at 68%, or two brackets at 95% confidence. Symbols used are:

G = Greater than 10%, or greater than value shown
* = Usual limits of determinations do not apply due to use of dilution techniques
- = Not looked for
H = Interference
N = Not detected, at limit of detection or at value shown
L = Detected, but below limit of determination or below value shown

Lower limit of determination in ash or ashed coal after allowing for necessary dilution

			REVISED 1972
Fe %	.002		0.001
Mg %	.005		0.002
Ca %	.005		0.002
Ti %	.0005		0.0002
Mn (ppm)	2		1
Ag	2		0.5
As	2000		1000
Au	50		20
B	50		20
Ba	3		2
Be	2		1.5
Bi	20		10
Cd	50		50
Co	7		5
Cr	2		1
Cu	2		1
La	70		50
Mo	7		3
Nb	20		10
Ni	10		5
Pb	20		10
Pd	5		2
Pt	70		50
Sb	500		200
Sc	10		5
Sn	20		10
Sr	10		5
Te	5000		2000
U	1000		500
V	15		7
W	200		100
Y	20		10
Zn	700		300
Zr	20		10

			REVISED 1972
Si %	Not looked for		0.002
Al %	.002		0.01*
Na %	Not looked for		0.05
K %	1.5		0.7
P %	.7		.2
Ce (ppm)	300		200
Ga	10		5
Ge	20		10
Hf	200		100
In	20		10
Li	100		100
Re	100		50
Ta	500		500
Th	500		200
Tl	100		50
Yb	2		1
Looked for only when La or Ce found:			
Pr	200		100
Nd	150		70
Sm	200		100
Eu	200		100
Looked for only when Y is found above 50 ppm:			
Gd	100		50
Tb	700		300
Dy	100		50
Ho	50		20
Er	100		50
Tm	50		20
Lu	70		30
Looked for only when Pd or Pt found:			
Ir	100		50
Os	100		50
Rh	5		2
Ru	20		10
Looked for only when requested:			
Cs			
Rb			
[illegible]			
Hg	1(15 g. sample)		

Field reviews are available on the occurrence of a few specific elements in coal, as a potential pollutant or as a possible mineral resource. The earliest studies of this type were joint surveys of coal as a source of uranium, conducted by AEC and the USGS. The published results of these surveys are entirely negative for present purposes, since the average coal in all regions was found to contain less than the detectable limit of 10 ppm by the methods of analysis used. Selected reports with good data have been excerpted and attached hereto for mercury (Appendix III), arsenic (Appendix IV), beryllium (Appendix V), germanium and gallium (Appendix VI), and fluorine (Appendix VIII).

2.5 Newer Methods of Analysis

The standard methods of analysis, is noted above, have a high limit of detection for most of the seven trace elements listed as hazardous. This is linked to their voltaility as the element, or as compounds formed furing analysis. Many of the newer procedures are methods which do not require preliminary ashing or destruction of the sample, which is time-consuming, expensive, and a serious potential source of error. The organic matter present in the coal is the principal source of interference in many trace element determinations, and a common prelude to the measurement is a procedure to eliminate or reduce this interference. The extent to which this destruction of the sample must be pursued, before interference in the final determination is minimized or eliminated, varies widely. In some instance no such treatment is required to complete the measurements, without any kind of chemical attack upon the sample.

One method of non-destructive analysis is X-ray fluorescence, which utilizes the emission of radiation from a sample as a result of bombardment. In this instance the bombarding radiation is X- or gamma-rays from a suitable source, while the emitted radiation is the characteristic X-rays which arise from the components of the sample. This technique has found considerable application in the oil industry and in coal research, and more recently in the analysis of particulates from air sampling programs. The method is extremely rapid, but in complex materials is likely to suffer from interference. It is best used when one or a few elements are to be determined in an essentially constant matrix and where there are many similar samples to measure so that the necessary, and generally lengthy, calibrations and corrections are worth carrying out. Examples are the routine determination of tetraethyl lead in gasoline, or nickel and vanadium in various petroleum fractions.

Neutron activation analysis can also be virtually non-destructive. Many elements, when bombarded with slow neutrons, give rise to radioactive species, and these often emit gamma-radiation. When the other components of the sample do not interfere, it is possible to identify and determine the radioactive species by means of the gamma photons that they emit, and from this, to measure the amount of the element present in the sample. An easy example of the application of this technique can be found in the determination of sodium in fuel oil where the very energetic gamma of 2.75 MeV is readily measured. Interference effects are important in the presence of large amounts of inorganic ash, as in coal, and the analysis of an unknown sample may require a new calibration to take them into account. Instances are known where neutron activation gives a completely false reading due to the synthesis of elements during neutron bombardment (e.g., NBS studies on strontium in granite).

Activation analysis requires the use of a nuclear reactor, expensive equipment and facilities, and experts in the field. In addition, the time required from sampling to results is relatively long and may be expensive. If none of these considerations are objectionable, it has the advantage of being able to identify and quantify a large number of elements in a single small sample. Collaborative tests are still required to confirm its applicability to many of these elements in coal. A major difficulty is the necessity of calibrating interference effects with predetermined samples having a composition essentially the same as the unknown. In trace metal analysis, changes in interactions with other background elements present in even the smallest amounts can cause large deviations in the values reported. This uncertainty can be gradually eliminated with experience in the analysis of coals. For specific elements, such as mercury, enough data are now at hand to confirm the reliability of the method.

Atomic absorption spectroscopy is a combination of emission and absorption phenomena. Its sensitivity can be a thousand times that for X-ray fluorescence, which cuts off above trace levels for some elements. In atomic absorption the sample in solution is atomized into a flame or alternate energy source, producing atomic vapor of the element in question. Monochromatic light of the same wavelength as that of the desired element is passed through the sample vapor, and the atoms present in the unexcited or ground state absorb radiation from the light source in proportion to their amount. Atomic absorption is easier to operate than are spark spectroscopy and X-ray fluorescence and somewhat cheaper to purchase, although it measures only one element at a time. Improved methods are now being developed, including larger samples and special vaporization procedures, which make it possible to apply this method to mercury, cadmium, selenium and arsenic. These methods are just now being developed sufficiently to produce results in field surveys.

3. Distribution of Elements

3.1 Sulfur and Rank in U.S. Coals

Sulfur is the only element for which ample data are available for a complete picture of geographical distribution by states and regions. It is always present in coal, and it contributes to net heating value. It is regarded as an unwanted constitutent, both because of air pollution and because it contributes to boiler deposits which may reduce efficiency and lead to boiler corrosion. The analysis of coals for sulfur content is a routine procedure and thousands of results are available, covering all U.S. coals for the past 60 years. A comprehensive review of these data and their geographical implications was prepared by the USBM in 1966 (see Appendix IX). Coal cleaning is regularly employed to reduce this sulfur content of commercial coals, and the USBM data are mostly on cleaned coals, as marketed(3).

Experts at the USBM, USGS and elsewhere have indicated to us that the 1966 conclusions are based on representative data, and will not be affected by any more recent information. The one thing which has changed is the public demand for low sulfur fuels, as reflected in the Clean Air Act of 1967 and subsequent regulations. The status as of 1966 was stated clearly as follows (3): "Except for special-purpose coals such as those used for the production of coke and ceramics where impurities in the fuel contaminate the end product, the amount of sulfur in coal has been only a minor consideration in the selection of a particular coal for fuel. Major considerations, particularly for the coals used to generate electric power, have been availability and cost. An increased national concern for control of air pollution, however, particularly that resulting from the emission of sulfur oxides in stack gases to the atmosphere, has led to more rigid specifications on coal quality, and the sulfur content of coals will become increasingly more important in the future.

"The sulfur content of United States coals varies widely, ranging from a low of 0.2 percent to as much as 7.0 percent as mined, by weight, on a dry basis. Perhaps as important as the amount of sulfur, however, is the manner in which sulfur occurs. Generally, sulfur is present in coal in three forms: as organic combinations, as pyrite or marcasite, and as sulfates. The forms of sulfur are important because they generally indicate whether any appreciable reduction in sulfur can be achieved through conventional cleaning processes. Sulfur held in organic combinations generally predominates in low-sulfur coals, and cannot be separated from the coal substance by conventional cleaning. Sulfate sulfur is generally quite low and usually is of not great concern. The pyritic sulfur, however, can vary from a low of 40 percent to as high as 80 percent of the total sulfur. With increasing total sulfur, both the pyrite and organic forms tend to increase, although there is no direct relationship between the two. Some reduction of pyritic sulfur can be achieved by crushing and various cleaning processes, depending upon the manner in which it is dispersed in the coal.

"Pyrites are distributed in coal in many ways. The two minerals pyrite and marcasite have the same chemical composition, FeS_2, but differ in physical structure. They often are difficult to distinguish from each other, and unless there is definitie evidence to the contrary, it is convenient to group them as iron pyrites. They may occur in lenses and bands, joints or cleats, balls or nodules, and as finely disseminated particles. The size and distribution will greatly affect the amount that can be removed by conventional coal preparation methods. Coarse crushing may release much of the pyrite in the lenses, bands, and larger particles, for subsequent removal by mechanical cleaning. If the pyrite is finely disseminated it cannot be removed unless the coal is very finely crushed, and the pyrite separated from the coal substance by special treatment".

Zinc, mercury, arsenic, nickel, cobalt and copper all tend to be associated with the pyrites fraction, as the metal sulfides. Similarly, selenium when present tends to be in the form of selenopyrites, replacing a part of the pyritic sulfur. These associations with a much larger amount of FeS_2 and its degree of dispersion have an important bearing on the capability to recover or to remove these trace elements by coal cleaning.

The connotation of high-, medium-, or low-sulfur coal varies somewhat in practice, depending on the end use involved. For example, coking coals are considered high in sulfur content if they exceed 1 percent, whereas 1 percent sulfur content coal in boiler fuel would be considered low.

For the USBM discussion, coals are arbitrarily labelled according to sulfur content as low sulfur--1.0 percent or less; medium sulfur--1.1 through 3.0 percent; and high sulfur--3.1 percent or more:

Total U.S. reserves of coal of all ranks are estimated at 1,567,000 million tons, based on USGS data as of January 1, 1965. Approximately two-thirds of the estimated reserve may be considered low-sulfur coals, largely because more than one-half of the total is composed of low-rank coals (subbituminous and lignite) which generally contain 1 percent or less sulfur. Most of these reserves are in areas in the Western United States which are not highly industrialized, and original reserves of these coals, unlike those in the East, remain virtually intact.

All of the lignitic coal reserves, with the exception of small deposits in Alabama, are situated west of the Mississippi River; about 98 percent of the total is located in North Dakota and Montana. Approximately four-fifths of the North Dakota reserve has a sulfur content of 0.7 percent or less and about nine-tenths has no more than 1.0 percent sulfur. The Montana deposits, which are located in the eastern part of the State, run slightly higher in sulfur content than those of North Dakota, although about 69 percent contain 0.7 percent or less sulfur.

Reserves of subbituminous coal also are concentrated in the Western States, with about 60 percent of the total occurring in Montana and Wyoming. Most of the remainder is in Alaska, New Mexico, and Colorado. The subbituminous coals generally are low in sulfur, although there are some instances in Montana where sulfur is as high as 2 percent.

Of higher rank or bituminous deposits, about two-thirds are located in the States east of the Mississippi River. The coalfields, or deposits in Illinois, Indiana, and western Kentucky contain 29 percent of the estimated remaining bituminous-coal reserve, but Illinois alone has the largest bituminous reserve of all States. Coals in these States are generally higher in sulfur, with almost 80 percent of the reserves containing more than 3 percent sulfur. There are, however, several small deposits of low-sulfur coals in southern Illinois and Indiana where sulfur content averages 1.5 percent or less.

The Appalachian Region, which stretches northeastward from Alabama through Tennessee, Virginia, West Virginia, Ohio, and Pennsylvania, is the largest depository of high-rank bitumunous coal, with approximately 31 percent of the total remaining reserve. One of the characteristics of the Appalachian Region coals which enhances their value is their ability to coke or agglomerate when heated in the absence of, or with a limited supply of, air. All of the coals are not used for cokemaking, however, because some contain more sulfur than is desired for metallurgical-grade coke. We have more information on the quality of these coals than for any other region in the country. This is due to the many analyses of the coals made by Federal and State agencies in connection with the use of these coals, not only for cokemaking, but for light, power, and heat in the industrial, commercial, and residential sectors of the economy.

West Virginia ranks second in total bituminous-coal reserves, but first in reserves of bituminous coal among the states in the Appalachian Region. Approximately 46 percent of West Virginia's reserves are low-sulfur coals and 45 percent are medium-sulfur, making a total of 91 percent of the reserve having a sulfur content of 3 percent or less.

Pennsylvania ranks third in the Appalachian Region in reserves of bituminous coal. The bituminous beds of this State vary in sulfur content, but 85 percent of the reserve contains 3 percent or less sulfur, and 35 percent has a sulfur content of no more than 2 percent. The central Pennsylvania beds, including both medium- and low-volatile coals, generally contain less sulfur than those in the western part of the State.

Deposits of anthracite and semianthracite occur in seven States, but more than 80 percent of the reserve of this rank is found in northeastern Pennsylvania. The sulfur content of Pennsylvania anthracite is generally under 1 percent, with a large proportion of the reserve averaging between 0.6 and 0.7 percent. The small semianthracite coal reserves of Virginia are also low in sulfur, but the Arkansas deposits of semianthracite are relatively higher, ranging from about 1.4 to 3 percent.

Correlations between sulfur content and the location of coals within each producing region have been worked out in considerable detail, on a state or county basis (see Appendix IX). The overall picture for remaining reserves in the major U.S. producing regions is shown in Table IX. This table was obtained by consolidating the values for all coals in each state (counting "0.7 percent and under" as 0.5% for the average, 0.8 and 1.0 as 0.9, 1.1 to 1.5 as 1.3, ..., 3.6 to 4.0 as 3.8, and 4.1 or more as 4.5).

The distribution of sulfur in coals on the basis of production instead of reserves is much the same, but with more emphasis on bituminous (including subbituminous) coal. Total U.S. production shifted even more away from anthracite coal during the years 1964 to 1970 (USBM, Minerals Yearbook):

TABLE 9

SULFUR CONTENT OF U.S. COALS BY REGION(1)

Region and States	Production(2) (M Tons) 1969	Production(2) (M Tons) 1970	Estimated Remaining Reserves (Million Tons) 1965	Bituminous	Sub-Bitum	Lignite	Anthracite	Average for State	Average for Region
Appalachian									1.8
Alabama	17,456	20,560	13,597	1.5	0.5	1.3	0.5	1.5	
Georgia	NA	NA	76	.9				.9	
E. Kentucky	61,584	72,502	29,414	1.0				1.0	
Maryland	1,368	1,615	1,180	3.1				3.1	
Ohio	51,242	55,351	42,024	3.4				3.4	
Pennsylvania	89,104	90,220	70,162	2.6			0.5	2.0	
Tennessee	8,082	8,237	1,859	2.0				2.0	
Virginia	35,555	35,016	10,155	0.9			0.5	0.9	
W. Virginia	141,011	144,072	102,666	1.4				1.4	
Interior Eastern									3.4
Illinois	64,772	65,119	135,889	3.5				3.5	
Indiana	20,086	22,263	34,841	2.9				2.9	
W. Kentucky	47,466	52,803	36,895	3.5				3.3	
Michigan	NA	NA	205	3.8				3.8	
Interior Western									3.7(4)
Arkansas	228	268	2,396	1.5		0.6	2.1	1.5	
Iowa	903	987	6,522	4.5				4.5	
Kansas	1,313	1,627	20,738	3.6				3.6	
Missouri	3,301	4,447	78,760	4.2				4.2	
Oklahoma	1,838	2,427	3,302	2.0				2.0	
Texas	NA	NA	14,880	2.3		1.3		1.8	
Western									.8
Arizona		132							
Colorado		6,025	80,754	.7	.6		0.9	.7	
N. Mexico	4,471	7,361	61,427	.7	.6		0.9	.6	
Utah	4,657	4,733	27,808	1.4	1.3			1.4	
Washington	58	37	5,885	.7	.6	0.9	0.5	.6	
Wyoming	4,602	7,222	120,722	.7	.9			.8	
Northern Plains									.6
Montana	1,020	3,447	221,702	2.6	.6	.7		.7	
N. Dakota	4,704	5,639	350,698			.6		.6	
S. Dakota	NA	NA	2,031			.9		.9	

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(1) Based on USBM I.C.8312, Sulfur Content of U.S. Coals (1966). See Appendix VIII.

(2) USBM Minerals Yearbook-1969 and Preprint-1970.

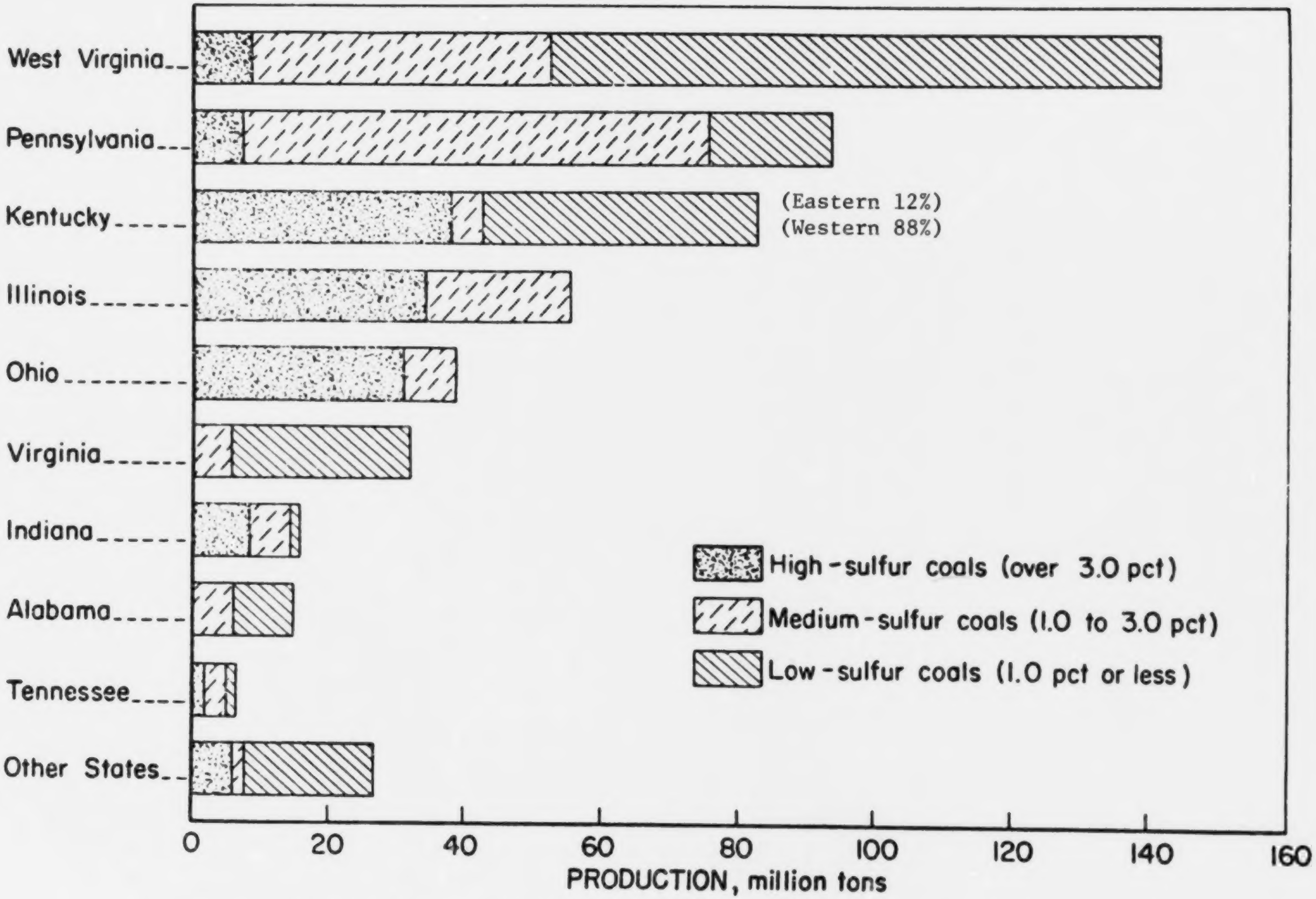
(3) Recalculated from Table A-1 using arbitrary mid-range values of 0.5 for 0.7% S or less, 0.9 for 0.8-1.0, 1.3 for 1.1-1.5....3.8 for 3.6-4.0, and 4.5 for over 4.0.

(4) Value of 4.5 is probably low for high sulfur reserves in Interior Western Region, and high in Interior Eastern.

	MM Short Tons		% of All Coals	
	1964	1970	1964	1970
Anthracite	17	10	3.4	1.6
Bituminous	484	597	96.0	97.4
Lignite	3	6	0.6	1.0

The geographical distribution for producing states and major coal regions is shown graphically in Figure 3, for low-, medium-, and high-sulfur coals. In general, the Appalachian region produces low to medium sulfur coals. The Interior Eastern region which has been extensively mined and the Interior Western region which is the next most available in terms of distance from markets are both high in sulfur. The Western and Northern coals are much lower in sulfur but less accessible, and of lower rank. This means that they are suitable for local use, in remote areas, but not for long distance transportation.

Figure 3



Total Coal Production of All Ranks, by State and Sulfur Content, in the United States, in 1964.

3.2 Mercury: Averages and Extremes

Mercury has received major attention in the past two years as a hazardous air pollutant, and concerted efforts have been made to supply missing data on its analysis in fossil fuels. Part of this concern is based on the widely quoted but misleading statement that the amount of mercury released to the environment by the burning of coal is comparable to that emitted as waste from all industrial processes. This statement is taken from a 1971 article by Joensuu(5).

Joensuu states that "The analyses were performed on a relatively small number of samples that are not representative", but this qualification has been completely lost in subsequent references. The difficulty starts in the original article, however. The author finds that his method of analysis is confirmed by agreement between his average of .19 ppm for coals from Illinois (5 samples) and the average value of .18 ppm reported by the Illinois State Geological Survey (53 samples)(6). He then recognizes that his sampling of 36 U.S. coals gives an average which is too high (3.3 ppm), but apparently gives his extreme values equal weight with the samples determined elsewhere and chooses a "conservative estimate" of 1 ppm as typical of all coal produced. On this basis, he calculates 3000 tons of mercury per year as released by coal combustion, worldwide, and finds this quantity comparable to the 10,000 tons per year consumed industrially, most of which is eventually discarded to waste. This is the origin of the statement so widely quoted. The more representative basis of .18 ppm as typical for coals would give 540 tons of mercury from combustion stacks as against 10,000, which is less than "comparable" by an order of magnitude.

Comprehensive studies of U.S. coals during 1971 and 1972 have failed to find a single commercial supply which runs as high as 1 ppm(10,17). The newer methods of analysis have a limit of detection of about .01 ppm. This is approximately the same by neutron activation and by flameless atomic absorption, using a double gold amalgamation procedure to remove interferences without loss of mercury (9). Data which permit a good survey of geographical distribution by producing region are presented in Table X. These have been assembled by compiling results published by Illinois(6), the Bureau of Standards(9), and USGS analyses for the Southwest Energy Study(8). The range and average values reported by the State of Illinois are close to the average for the U.S. as a whole, possibly a little high. A proper U.S. average might be close to .15 ppm. This is almost identical to results now being obtained in studies at the Oak Ridge National Laboratories in a field survey of coals currently consumed in various power plants by TVA(17).

The reason for this confusion lies not in Joensuu's method of analysis, which is reliable, but in the selection of samples which are essentially museum specimens, and allowing them to be included in a result reported as "average". Joensuu's analytical procedure is confirmed in a 1972 report on "Mineral Matter and Trace Elements in U.S. Coals" prepared for the Office of Coal Research by Penn State University, which supplied him his samples(18). This report in turn analyzes 57 samples of coal but identifies 41 of the 57 as lithotypes, selected for their interest as mineral specimens. Its conclusions as to mineralogy are instructive and well documented. Unfortunately it

TABLE 10

GEOGRAPHICAL DISTRIBUTION OF MERCURY 1971-72 RESULTS; PPM ON COAL

		Analysis by				
Region	State	Neutron Activation (Illinois)(1)	N.A. + AA (N.B.S.)(2)	Flameless-AA (USGS-SW)(3)	Average	Total No. of Samples
A	Pennsylvania	.16, .28	.15		.20 (2.0*)	3
	Ohio	.10, .13, .15	.14, .28, .49		.21	6
	West Virginia		.07, .18		.12 (6.6*)	2
	E. Kentucky				(.25*)	
IE	Illinois	.04-.49, .60, 1.15			.18 (.19*)	53
	Indiana		.08		.08 (.31*)	
IW	Missouri		.19		.19	
N	Montana	.06	.07, .09		.07 (33.*)	
W	Utah	.04		.03-.08	.05	15
	Colorado	.02, .02	.05	.03-.06	.04 (.22*)	3
	Wyoming			.03-.06	.05 (18.6*)	6
	Arizona	.02	.06	.04-.08	.05	6
	Nevada			.04-.05	.05	7
	New Mexico			.05-.29, .69, 1.20	.15	37

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1. Illinois State Geological Survey, Bulletin EGN-43 (1971).

2. National Bureau of Standards (1972).

3. Southwest Energy Study, Appendix J, (Draft Jan. 1972).

* Values from Joensuu (1971) shown for comparison, including lithotypes.

also constructs average data by coal rank and area, and draws conclusions based on a comparison between whole coal in one area and lithotypes in another. Any conclusions drawn on such a basis must be confirmed by representative data from other sources, before they can be accepted.

The Southwest Energy Study has made a detailed survey of the mercury content of coals accessible to the large new power plants near the 4-Corners area. This covered ten mining locations and 75 samples. Analyses were made by the USGS laboratory at Denver using an improved method whose precision is ± .01 ppm (see data in Appendix III). Coals from nine locations ranged between .03 and .15 ppm of Hg in all samples with an average of .06 ppm, and .05 as the most frequent value. One location in New Mexico showed an average of .23 ppm, based on 16 samples, including two high values at .69 and 1.20 and 14 which ranged between .04 and .29 ppm. The five highest values from this mine (.24, .69, 1.20, .20 and .29) were all from a set of 14 core drill samples which showed anomalously high levels for other metals (zinc and lead), and sample contamination is suspected. While additional data are required, the average for this mine from two other samples was .05 ppm.

This study fully confirms on a smaller scale the general observation that the mercury content in most coals is quite low, less than .2 ppm, and that occasional extremes as high as 1 ppm are limited to a few specific locations. Even where these extremes occur the average Hg content for the mine is far below the extreme, .23 in this case vs 1.20, and not necessarily much different from the average for other coals.

3.3 Data on Trace Elements

The method of interpretation and presentation used for trace elements in coal in this report proceeds element by element, for major geographical regions, using the correlation concepts of variance and extremes discussed above (Section 2.2). Separate columns of data are provided first for the USGS studies on the coal basis by Zubovic, et al, giving his averages by area, the 90+% range as defined for columnar bed samples, and extremes beyond this range. Analyses of the ash of delivered coals are presented in a separate column, for comparison, based primarily on the extensive data obtained by Abernethy, et al on USBM samples. Analyses both on a coal basis and on ash have been augmented by data obtained from the Southwest Energy Study, and from specific references as given for other elements.

The data selected are summarized in Table XI. Marked copies of the USGS data (Bulletin 1117) are given in Table XII. This shows the specific data points selected as high and low values (underlined) or as extremes (+), or excluded as coal blocks representing less than 75% of a columnar sample (ticked).

TABLE 11

TRACE ELEMENTS IN U.S. COALS, (ppm), BY GEOGRAPHICAL REGION[1]

ELEMENT (variance) (3)	Range of Analysis, ppm on Coal: Averages (2) by Region (1) and Area	90 + % Range for Beds (4) within Region	Bed Extremes (occurrence) (5)	Wt. % on Ash: Averages for States, by Region (6)	Comments
Hazardous					
Be	2.0-3.1	A .6-4.1	11 (1:44)	A .001-.007	Wide variability from block to block within a bed.
	2.5	IE .6-7.6		IE .001-.004	Regional effects observed, concentration higher near the edge of a bed or basin, less in center.
5	.64-2.3	IW .1-5.5		IW .000-.001	
	1.5	W <.1-3.1		SW .0002-.001	Be higher in organic fraction of coal, low in associated mineral fraction.
		N .12-3.9		N .000-.001	
F	50-120	A 10-190			Mostly narrow range; high in some western areas.
	50-100	IE 50-167			
3	65-120	IW 50-120			
	65-160	SW 60-220			
	65	N 60-70			
As		A 3-59	114 (1:15)	A 0 (33%)-.016	Not distinctive, marked local high concentrations (arsenopyrites), wide range in each area.
		I 8-45		I 0 (39%)-.012	
		SW 73		W 0 (88%)-.007	
Se		SW .50-3.9			Very little data; associated with mineral fraction (selenopyrites) probably higher in eastern coals.
Cd		SW .0-.06		<.005	Very little data: regularly less than detection limit of .005% on ash by spectrographic analysis.
Hg	.12-.21	A .07-.41			Widely distributed at low levels, except beds near Hg ore bodies can reach very high concentration; selected mineral specimens (lithotypes) of 1-33 ppm reported from Pa., W. Va., Wyo., Mont.
	.13	IE .04-.49	.60-1.15 (2:55)		
3	.19	IW .19			
		SW .01-.25	.47-.90 (2:74)		
	.07	N .07-.09			
Pb		A 4-14	34	A .001-.008 .014-.332 (3:39)	Narrow range except for beds near Pb ore bodies.
		IE 8-14	37	IE .007-.028	
3		IW 4	120-170	IW .003-.020	
		W 5-10		W .001-.004	
		N 7		N .002-.004	

TABLE 11 (Cont'd)

ELEMENT (variance) (3)	Others (Coal Basis)	Range of Analysis, ppm on Coal			Wt. % on Ash	
		Averages (2) by Region (1) and Area	90 + % Range for Beds (4) within Region	Bed Extremes (occurrence) (5)	Averages for States, by Region (6)	Comments
B		22-55	A 4-56	72 (1:44)	A .014-.056	Wide variations esp. in bottom layer, from B picked up from soil by coal-forming plants during growth. Concentration high in low rank coals.
		96	IE 13-198	4 (1:47)	IE .069-.080	
	6	18-73	IW 2.5-180		IW .018-.083	
					SW .020-.070 .15-.20 (8:71)	
		116	N 78-201	356 (1:12)	N .034-.048	
V		19-25	A 2.4-44		A .023-.042	Not distinctive (i.e., no marked geographical correlations)
		35	IE 8.7-67	96,182 (2:44)	IE .030-.034	
	2	17-22	IW 4.7-44	69,71 (2:52)	IW .015-.038	
					SW .005-.015	
		16	N 5.3-29		N .009-.010	
Cr		11-15	A 4.1-25	32 (1:44)	A .014-.026	Not distinctive.
		20	IE 5-54		IE .018-.025	
	2	12-17	IW 4.4-38	61 (1:52)	IW .015-.030	
					SW .007-.010	
		7	N 2.6-19		N .002-.003	
Co	3.5	4.1-6.7	A .5-12	16,19 (2:73)	A .014-.021	Not distinctive
		3.8	IE 1.2-10		IE .013-.023	
	2	4.4-5.4	IW .4-16	44 (1:52)	IW .023-.055	Co/Ni may be associated with pyrites, as the sulfides
					SW .001-007	
		2.7	N .7-7		N .006	
Ni		9.7-20	A 2.4-37	46 (1:44)	A .013-.028	Not distinctive; picked up more easily than Co by coal-foaming plants. May be increased markedly, with other trace elements, in weathered coals (X in Figure 4).
		15	IE 5-37	46 (1:34)	IE .017-.031	
		11-24	IW 1.1-47		IW .033-.077	
					W .005-.011	
		7	N 1.5-15		N .001-.003	
Cu		14-17	A 3.4-37		A .008-.016	Not distinctive; occasional high values found in selected mineral specimens (lithotypes).
		11	IE 3.1-25		IE .007-.010	
	1.5	11-13	IW 2.9-37		IW .006-.015	
			SW 1-15		W .005-.012	
		15	N 2.8-16	47 (1:12)	N .001-.003	

TABLE 11 (Cont'd)

	Range of Analysis, ppm on Coal			Wt. % on Ash	
ELEMENT (variance) (3)	Averages (2) by Region (1) and Area	90 + % Range for Beds (4) within Region	Bed Extremes (occurrence) (5)	Averages for States, by Region (6)	Comments
Zn 5	4.4-12 44* 22-53* 59*	A 0-36 IE 0-53 IW 0-35 SW 1-17 N 0-23	72-600 (5:34) 230,290 (2:52) 331 (1:12)	A .020-.029 IE .051-.120 IW .019-.133 W .010-.043 N .025-.034	*Older high values are suspect, because of frequency and ease of contamination of samples in the field. More accurate data show some correlations with high concentrations near Zn ore bodies.
Ga 4	4.1-6.8 4.1 1.4-3.7 5.5	A 1.3-12 IE 1.5-8 IW .5-7.3 N 1.0-13	11,18 (2:34) 19 (1:52)	A .002-.010 IE .003-.004 IW .002-.007 SW .001-.005 N .002-.004	No geographical areas of concentration; low in the Arkansas/Oklahoma area, far from source rocks. Accumulates in fly ash, where normal ~60 ppm may be useful as a mineral source.
Ge >10	3.3-9.6 13 1-22 1.6	A 0-18 IE .4-27 IW 0-30 N 0-7	38 (1:34) 45,48 (2:52) 15 (1:12)	A .001-.006 IE .008-.014 IW .001-.013 W .001-.003 N .001-.003	High variability between top/bottom layers of coal and center of the bed; can give higher average for thin or lenticular beds. Coal fly ash (~250 ppm) may be a useful mineral source.
Mo 4	1.5-5.8 4.3 2.6-4.3 1.7	A .4-8.7 IE .6-8.5 IW 0-7.3 N .1-3.4	18,42 (2:44) 12-18 (3:34) 12,16 (2:52)	A .002-.012 IE .005-.008 IW .005-.013 W .001-.003 N .003-.004	Only element whose enrichment correlated with U in spot locations, in USGS/AEC studies; variance would change to 3 by excluding one extreme value (in Alabama) from average for A.
Sn (3)	(.1)-.9 1.5 .6-1.6	A 0-2.1 IE .1-5 IW 0-5 N .2-4.3	22 (1:47)	A .001-.006 IE .001-.005 IW .001-.002 W .001-.002 N .001	Uniform, small amounts; high values in occasional lithotypes.
Y 3	9.6-22 7.7 7.2-7.9 13	A 6.6-28 IE 1-13 IW 1.7-27 N 1.0-27	41,42 (2:44) 33 (1:34) 35,48 (2:52)	A .005-.022 IE .009-.014 IW .010-.013 W .005-.010 N .006	Y/La ratio is more significant than absolute values; ratio decreases linearly (3:1 to 1:1) with distance of coal bed from source rocks during formation.
La 3	8.3-11 5.1 2.9-7.2 9.5	A 0-25 IE .2-24 IW 0-37 N 0-22	36 (1:34) 84 (1:52)	A .010-.018 IE .011-.017 IW .010-.013 W .005-.015 N .010	Quite uniform as a percent on ash.

TABLE 11 (Cont'd)

ELEMENT (variance) (3)	Range of Analysis, ppm on Coal Averages (2) by Region (1) and Area	Range of Analysis, ppm on Coal 90 + % Range for Beds (4) within Region	Range of Analysis, ppm on Coal Bed Extremes (occurrence) (5)	Wt. % on Ash Averages for States, by Region (6)	Comments
U		A 10	60, 70		-- Mostly none, or in bottom few inches only
		IE 10	80		-- Same
		W 10-160	620		-- Uraniferous coals average 30 ppm, thin top layers higher.
		N 50-240			-- Large tonnages of lignite at 80 ppm, occasional beds as high as 2-5% uranium or ash.
Others (Ash Basis)					
Li				A .014-.106	Variable, probably depending on water contact.
				IE .017-.039	
				IW .005-.030	
				W .010-.028	
				N .010-.022	
Sc				A .006-.014	Wider range in western coals. Coal ash is a possible source, in view of scarcity of ores.
				IE .007-.008	
				IW .004-.005	
				W .001-.009	
				N .003-.005	
Mn				A .003-.054	Uniformly present in small amounts; wide range in lithotypes.
				IE .020-.062	
				IW .015-.043	
				SW .005-.020 .070,.20 (2:71)	
				N .030-.046	
Sr				A .051-.154	Narrow range, usually correlates with Ca.
				IE .058-.070	
				IW .060-.075	
				W .040-.092	
				N .061-.066	
Ba				A .045-.127	Uniformly present; high values in lignites presumably related to regional Ba concentrations.
				IE .029-.047	
				IW .015-.100	
				SW .030-.500	
				N .265-.300	
Yb				.0003-.0011	Present widely in low amounts.
Bi				.0001-.0002	Uniformly present in very low amounts.

Footnotes:

(1) A = Appalachian (Pa, Md, Va, W. Va, Ohio, Eastern Ky, Tenn, Ala)
IE = Interior-Eastern (Illinois, Indiana, Western Kentucky)
IW = Interior-Western (Iowa, Missouri, Kansas, Oklahoma, Arkansas)
W = Western (Rocky Mountain and Pacific)
SW = 4 Corners Area (Arizona, New Mexico, Colorado, Utah)
N = Northern Plains (Montana, North and South Dakota)

(2) Averages by regions or areas, coal basis, from USGS Bulletin 1117.

(3) Ratio of highest to lowest averages, for regions or areas.

(4) Range for 90% or more of beds (of which 75% or more of coal in a columnar sample was analyzed), omitting extreme values which appear to be exceptional.

(5) Occurrence given as a ratio of number of extreme values reported to total number of beds (of which 75% or more was analyzed).

(6) Ash values mostly from USBM RI 7281 and Southwest Energy Study, rounded to three significant figures.

TABLE 12

COMPARISON OF COALS FROM VARIOUS REGIONS OF THE UNITED STATES

Average minor-element contents, in parts per million, of coals from various regions of the United States

Element	Northern Great Plains province	Eastern Interior region	Appalachian region	Element	Northern Great Plains province	Eastern Interior region	Appalachian region
Be	1.5	2.5	2.5	Ga	5.5	4.1	4.9
B	116	96	25	Ge	1.6	13	5.8
Ti	590	450	340	Mo	1.7	4.3	3.5
V	16	35	21	Sn	.9	1.5	.4
Cr	7	20	13	Y	13	7.7	14
Co	2.7	3.8	5.1	La	9.5	5.1	9.4
Ni	7.2	15	14	Ash average (in weight percent)	13.42	6.16	6.11
Cu	15	11	15				
Zn	59	44	7.6				

Average minor-element contents, in parts per million, of coal from 3 areas of the Appalachian region

Area	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
Northern (Ohio, Md., Pa.)	2.4	55	407	21	15	4.7	20	15	12	6.8	9.6	3.8	0.1	22	8.3
Central (Ky., Northern Tenn.)	3.1	22	340	19	11	4.1	9.7	14	4.4	4.5	3.3	1.5	.9	9.6	11
Southern (Ala.)	2.0	24	350	25	14	6.7	15	17	8.6	4.1	6.4	5.8	.3	13	5.8

Comparison of the average minor-element content of coal from the Western and Eastern regions of the Interior coal province

[In parts per million]

Element	Western region			Eastern region
	Oklahoma-Arkansas basin (32 samples)	Iowa, Missouri, North Oklahoma (12 samples)	Total Western region (44 samples)	(47 samples)
Be	0.64	2.3	1.1	2.5
B	18	73	33	96
Ti	250	250	250	450
V	17	22	18	35
Cr	12	17	13	20
Co	4.4	5.4	4.6	3.8
Ni	11	24	14	15
Cu	11	13	11	11
Zn	22	[1] 32	[1] 28	44
Ga	1.4	3.7	2.0	4.1
Ge	1.0	22	6.8	13
Mo	2.6	4.3	3.1	4.3
Sn	1.6	.6	1.3	1.5
Y	7.2	7.9	7.4	7.7
La	7.2	2.9	6.5	5.1
Ash	[2] 5.11	[2] 7.45	[2] 5.75	

[1] High zinc samples Mo-T-M (loc. 5, fig. 2) and Mo-P-T (loc. 4, fig. 2) not included in average.
[2] Ash content, in weight percent.

MINOR ELEMENTS IN AMERICAN COALS APPALACHIAN REGION

—Average minor-element content of the columnar samples of coal

[O, below limit of detection; leaders indicate no data for element; *, not used in computing regional averages. Location of samples shown in table 1]

Sample	Percent of bed analyzed	Average ash percent	Averages (parts per million in coal)														
			Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
O-L-MK	100	11.07	1.6	26	510	23	21	9.2	37	21	17	7.5	6.3	5.3	0	23	17
O-Mal-MK	100	7.62	1.8	29	......	14	8.8	1.8	13	11	30	6.1	6.3	1.2	0	19	4.0
O-SB-MK	75	3.40	1.8	33	......	2.4	4.1	.8	2.4	3.4	27	1.3	1.0	1.3	0	......	......
O-SC1e-MK	98	8.29	1.5	......	......	21	7.9	2.5	6.4	13	0	4.9	3.8	1.2	0	41	6.9
O-SH-MK	90	19.20	2.6	......	830	31	19	2.9	9.9	12	14	6.3	4.0	1.3	0	23	25
O-W-MK	39	14.19	4.0	132	590	41	45	7.4	31	20	0	15	40	2.6	0	22	14
O-M-LK	100	11.46	2.4	......	......	12	12	1.9	6.2	20	27	5.1	5.3	2.2	0	12	3.0
O-Mag-LK	100	11.43	2.6	......	130	24	17	4.8	23	21	6.2	11	15	18	.7	20	4.6
O-Mal-LK	100	5.89	.7	......	......	17	12	4.6	22	16	5.6	7.7	13	8.0	0	14	0
O-Me-LK	100	15.52	4.1	......	......	11	14	4.1	46	26	2.1	7.4	5.7	3.5	0	23	10
O-P-LK	100	12.62	2.4	56	390	12	13	8.1	15	14	15	6.2	14	1.2	0	16	12
O-SC11-LK	100	6.98	1.3	......	110	17	8.4	2.0	23	17	5.7	6.5	5.6	5.3	0	25	0
O-SC1e-LK	100	6.06	2.4	......	......	24	15	2.4	19	16	0	8.7	0.5	3.2	1.0	24	1.8
O-SC2e-LK	90	11.70	3.2	......	......	42	17	8.0	32	19	2.1	12	14	5.7	0	21	2.1
O-SH-LK	100	11.73	3.3	......	320	11	4.7	5.5	8.0	6.0	14	3.2	5.7	1.8	0	22	4.7
O-T-LK	100	8.50	1.8	......	......	18	11	3.2	34	12	0	3.4	7.0	4.0	0	15	0
Pa-Pi-LK	73	11.83	3.7	......	......	20	12	3.2	7.9	17	6.7	4.8	3.7	.9	0	18	12
Md-Up-LK	90	11.55	2.4	......	......	33	32	12	28	15	26	6.2	6.4	1.2	0	42	24
Ky-UE-SL	97	2.63	1.2	41	330	21	14	5.5	15	10	0	5.2	0.8	1.8	1.0	6.7	6.7
Ky-Dis-H6	100	8.88	1.3	17	650	19	15	4.5	12	21	15	5.1	.6	1.0	1.9	11	12
Ky-Har-H6	100	4.60	.8	25	600	25	14	4.1	8.7	16	0	4.7	4.8	1.0	.5	8.4	14
Ky-BD-Le	100	3.18	1.1	15	380	13	9.6	3.8	6.1	8.0	0	2.6	.7	1.8	.4	8.1	8.6
Ky-Pu-Hi	56	3.50	4.4	13	300	52	17	1.5	14	18	0	7.0	5.6	2.1	1.5	14	5.7
Ky-Al H4	71	3.41	3.0	15	490	36	17	6.0	12	12	0	6.9	1.2	.8	.7	11	9.7
Ky-Col1-H4	100	2.54	.9	8.5	170	9.7	6.5	7.2	5.9	11	2.7	3.8	4.2	.8	0	8.8	6.0
Ky-Col2-H4	100	2.41	1.9	16	260	16	8.2	4.5	9.8	14	1.0	5.2	5.5	.9	.7	8.8	7.2
Ky-Sx-H4	31	6.46	19.1	4.7	370	10	9.4	9.3	7.0	11	2.7	12	3.0	.3	1.6	21	23
Ky-SL-Wh	100	3.52	.9	26	420	16	10	1.3	4.0	14	0	2.6	.7	.7	2.1	10	11
Ky-PC-Am	100	2.63	.8	28	240	14	11	1.0	2.8	10	0	4.0	2.7	1.3	2.0	9.3	8.4
Ky-EJ-F1	100	2.92	2.1	16	170	9.7	5.3	2.2	7.2	6.9	4.0	2.6	1.7	1.1	1.0	8.2	3.4
Ky-Hx-E1	93	2.29	1.6	17	240	7.4	4.9	.5	21	6.3	0	2.0	2.2	1.2	.4	5.5	4.9
Ky-W-E1*	29	5.71	4.0	25	350	27	11	7.4	15	21	16	11	11	1.3	0	11	11
Ky-B&S-E2	100	4.72	2.0	33	340	12	9.4	2.9	6.7	11	32	4.3	1.1	1.0	.4	6.7	9.0
Ky-Hop-E2	100	4.54	2.3	18	410	16	9.9	5.1	8.1	20	0	5.6	2.5	.6	.6	11	10
Ky-GV1E1	92	3.83	1.8	18	290	12	7.0	4.1	7.9	26	1.2	3.5	1.5	1.3	1.0	12	13
Ky-GV2E1	91	2.22	.7	49	170	20	8.4	1.8	6.8	10	0	2.5	.1	2.0	.4	8.6	8.5
Ky-Wo-J	100	1.45	2.3	15	110	14	5.7	4.1	8.4	8.1	0	2.7	1.1	.7	.4	6.6	3.6
Ky-HI-Hs	97	3.05	11	5.5	370	11	7.6	8.1	16	16	0	6.8	18	.4	.6	8.6	7.1
Tenn-R&P-D	35	3.32	.6	50	200	11	8.6	2.0	5.6	12	0	2.5	0	2.0	1.0	4.9	10
Tenn-A-J	50	2.53	.1	27	92	15	5.0	4.5	5.3	6.7	2.3	2.0	0	3.0	2.0	2.6	6.1
Tenn-D-J	42	3.13	1.6	25	170	17	7.8	3.7	11	23	6.1	2.7	1.0	3.2	.1	7.0	6.9
Tenn-E-J	42	10.22	2.3	16	540	39	25	8.4	22	29	23	8.3	14	5.6	0	14	22
Tenn-V-K	42	8.91	11	19	870	32	19	1.6	7.3	17	15	3.5	5.6	1.3	0.2	18	37
Tenn-Re-S*	7	7.58	2.3	4.6	310	23	15	3.0	6.1	5.3	0	3.8	3.0	0	0	15	15
Tenn-Va-S	48	6.56	.3	6.6	270	15	19	2.7	6.3	4.7	0	4.5	0	.8	0	6.4	13
Ga-B-5*	9	3.12	2.2	6.2	140	10	5.6	1.3	6.6	31	0	2.2	1.2	4.4	0	13	3.1
Ga-Bl-5	100	2.63	.6	3.5	68	7.5	6.7	8.2	9.0	14	1.8	1.7	.4	1.4	0	6.6	5.3
Ga-W-4	78	1.47	.8	7.8	120	13	9.4	4.7	9.0	9.1	6.3	1.6	.5	5.2	.2	7.9	9.6
Ala-Mi-B(E)	100	3.43	2.8	5.8	440	36	17	19	26	37	22	5.7	.4	4.7	.2	28	12
Ala-Mi-B	41	7.93	4.6	5.1	310	34	25	23	39	17	51	5.3	15	3.0	0	15	13
Ala-T-B	38	3.89	1.9	9.3	280	12	6.4	3.5	6.4	12	6.6	2.6	.1	5.6	1.1	6.6	9.8
Ala-TH-B	86	4.95	2.2	10	610	44	22	7.0	25	34	8.5	6.6	2.0	5.8	1.6	16	13
Ala-Mi-Mi	50	3.30	2.1	4.2	130	9.0	7.0	2.5	8.8	14	0	2.4	.2	1.9	0	11	5.2
Ala-T-Mi	60	4.47	2.0	7.7	230	18	14	7.9	19	21	39	6.7	3.7	5.5	.7	18	11
Ala-TH-Mi	100	5.01	2.3	3.9	280	11	8.6	3.8	8.6	7.6	22	2.5	4.5	2.4	.5	11	7.3
Ala-Da-P	47	3.58	1.2	6.0	120	22	11	3.6	6.2	18	0	7.3	4.1	2.5	0	13	2.9
Ala-G-P*	......	3.63	1.6	31	330	20	12	2.7	5.9	6.3	0	3.6	2.4	2.2	.9	10	11
Ala-G-NP	100	7.54	1.4	11	240	15	9.5	4.5	19	9.9	0	1.8	0	1.8	0	12	14
Ala-G-A	48	5.78	1.8	40	370	33	16	4.2	15	27	6.3	3.6	2.4	8.2	0	23	14
Ala-M-N	100	13.77	3.2	34	690	37	24	4.7	21	11	0	6.9	7.9	1.7	0	13	8.9
Ala-Ga-ML	100	4.85	1.3	72	940	41	25	3.9	12	11	0	6.5	1.2	1.4	0	13	6.8
Ala-Ma-J	62	4.87	3.8	33	180	23	11	3.5	11	7.2	0	3.0	60.0	3.1	0.1	11	4.8
Ala-Ma1-J	100	3.02	.9	55	130	24	9.4	3.2	9.3	18	0	1.4	.8	2.9	.7	11	5.0
Ala-De-BC	74	1.71	2.6	19	110	26	6.8	16	15	16	2.0	3.4	16	42	.4	8.7	7.5
Ala-Ga-BC	100	4.05	2.4	7.4	530	19	12	3.3	8.5	35	1.4	4.1	1.5	5.5	.3	12	8.9
Ala-H-BC	55	3.15	1.1	63	120	10	6.6	3.9	8.0	14	0	1.2	.4	2.1	.2	5.5	6.0
Ala-BD-W	36	4.69	1.1	9.4	270	11	12	2.6	9.4	13	10	1.5	.7	5.6	0	13	6.3
Ala-Z-M1	45	4.42	.8	25	320	38	16	8.2	14	8.8	0	6.1	7.5	2.4	0	7.9	11
Ala-Z-M2	35	4.51	1.2	53	590	33	16	4.7	13	10	3.8	4.0	.3	3.9	0	8.2	10
Ala-Z-M3*	10	5.62	1.4	39	350	35	14	11	11	14	0	2.8	0	6.9	0	13	14
Ala-FtP-UC*	5	5.86	4.1	1.2	180	18	23	5.3	12	4.1	0	2.9	12	1.2	0	23	12
Ala-FtP1-UC*	......	2.86	2.0	1.7	86	5.7	11	2.9	8.7	2.3	11	1.4	1.1	1.4	0	5.7	5.7
Ala-E-BC*	30	5.69	3.0	12	400	15	8.9	4.7	11	8.9	0	2.8	1.7	1.4	1.3	11	12

MINOR ELEMENTS IN AMERICAN COALS NORTHERN GREAT PLAINS COAL PROVINCE

—Areal distribution of the elements, in parts per million, of groups of bed samples

[0, below limit of detection]

Locality (fig. 2)	Beds averaged for the locality	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Mont-At, Mont-CMT	3.9	98.4	776	16.6	6.5	6.8	11.2	9.7	23.2	13.2	14.9	0.58	3.9	26.5	12.5
2	Mont-B, Mont-Su	2.8	82.3	1 140	22.3	8.7	3.2	4.4	15.8	0	9.0	6.6	1.3	3.4	26.7	22.3
3	Mont-S	1.5	356	357	15.2	4.1	1.7	4.0	7.0	0	3.4	1.3	2.1	4.3	10.1	18.3
4	Mont-KB-F, Mont-O-F, Mont-P-1 to Mont-P-3	1.1	97.2	630	27.5	10.9	1.5	9.1	47.5	0	11.2	.6	2.6	.4	8.7	18.8
5	Mont-K1-Ro, K2-Ro, Mont-N-Ro, Mont-Gl-BM, Mont-Ke-CC	2.6	91.2	251	11.6	5.9	2.2	3.2	10.6	0	4.5	2.1	.9	.23	9.3	10.6
6	Mont-FC-3	.11	139	260	13.5	5.0	.69	3.6	10.8	0	1.3	0	1.3	1.0	2.8	2.9
8	Mont-GS-10501 to Mont-GS-10510	1.7	......	......	14.6	19.2	3.0	3.7	9.2	0	6.4	0	2.0	......	15.8	.72
9	ND-BN-N, ND-BN-50N, ND-TT-N	.50	78.3	206	8.3	3.7	2.2	2.7	7.9	0	3.0	2.0	2.4	0	8.8	5.9
10	ND-Cu-GC	1.4	201	95.1	5.3	3.0	1.8	2.9	2.8	0	.96	3.4	1.4	1.2	4.4	0
11-12	ND-KR-Bu, ND-F-49874 to ND-F-49880	1.1	......	......	13.4	8.4	3.0	10.8	9.9	331	3.0	.46	.50	......	13.3	12.8
14	Wyo-Mo-Mo	.12	......	......	8.0	2.6	.88	1.5	7.1	14.8	1.3	0	.10	0	1.0	0
15	Wyo-Ch-He-1 to Wyo-Ch-He-6	.34	......	......	20.5	12.9	3.4	11.9	14.9	0	3.7	0	3.4	0	......	......

Average content of 15 minor elements in coal of individual coal-bed columns from the Eastern Interior coal region

[0, below limit of detection; * average of column not used in compiling averages, table 7]

Locality (fig. 1)	Coal column	Percentage of bed analyzed	Average ash (percent)	Average (parts per million)														
				Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Ill-D-7	94.2	3.92	3.2	183	354	11.9	10.1	1.9	6.0	3.1	1.7	2.4	4.5	0.8	0.5	5.1	0.9
2	Ill-Ha-7	100	4.40	1.9	133	382	22.5	19.3	1.8	6.2	9.0	0	3.0	14.1	1.5	.3	4.6	2.3
3	Ill-A-6	100	7.27	2.0	165	333	20.1	21.7	3.2	14	11.7	597	3.8	12	8.2	2.3	3.8	.32
4	Ill-C-6	100	5.83	1.8	186	447	23.0	23.7	2.5	18.5	16.6	53.0	4.5	10.7	8.1	0	4.2	1.2
5A	Ill-F-6	90.6	4.35	1.4	96	364	26.2	23.2	3.4	23.7	10.6	30.8	3.2	23.6	4.9	.51	4.3	3.5
5B	Ill-R-5	100	9.16	2.3	35	398	24.3	21.0	1.5	5.7	9.8	90.7	2.7	20.2	3.2	1.4	5.7	.5
6	Ill-M-6*	12.6	9.05	1.2	228	289	28.6	20.8	5.2	31.1	23.2	74.9	3.4	26.5	3.4	.6	9.2	12.5
7A	Ill-Ma-6*	11.2	16.51	.5	167	297	119	63.4	2.3	27.0	15.1	42.7	2.7	19.2	18.7	0	16.1	5.2
7B	Ill-Ma-5*		6.10	1.2	29	134	1,281	610	2.4	104	1.8	12.2	1.2	30.0	73.2	0	4.9	0
8	Ill-OB-6	100	3.47	1.6	116	348	25.5	17.0	2.4	13.7	6.4	2.7	2.3	3.9	1.1	1.1	3.6	7.4
9	Ill-Pa-6	30	9.57	1.8	200	418	34.7	24.5	3.5	10.9	41.4	268	7.1	34.2	3.5	0	17.7	2.0
10	Ill-Pw-6	83.1	4.73	1.4	131	278	23.0	18.6	1.8	10.0	6.9	1.6	2.9	9.4	6.8	1.9	5.8	4.2
11	Ill-S-6*	12.1	8.55	2.6	83	513	32.8	27.4	22.4	35.5	22.0	388	3.6	16.2	9.5	.8	10.2	29.2
12A	Ill-TrB-6	100	5.06	1.7	93	476	54.7	26.4	2.2	10.1	8.8	33.6	1.7	5.0	4.1	0	6.0	8.1
12B	Ill-TrB-5*	25	10.27	2.1	37	542	29.2	18.8	7.1	17.2	15.8	27.8	4.2	24.4	2.2	0	8.6	19.3
13	Ill-TrP-6*	4.5	19.92	4.0	100	209	15.9	16.9	6.0	41.8	12.9	5,570	.1	40.7	1.0	0	4.0	9.9
14	Ill-V-6*	29.6	7.6	1.3	82	309	43.3	179	15.1	12.2	11.1	283	5.7	18.0	9.3	.6	5.0	2.0
15	Ill-BB-5*	21.1	11.87	2.2	37	420	484	109	9.0	79.4	41.7	323	5.0	33.8	3.2	.7	16.2	8.8
16	Ill-B&W-5*	32.5	13.69	1.7	46	351	407	61.8	2.7	20.2	10.4	0	2.6	17.4	16.7	0	4.5	7.1
17A	Ill-E-5	100	6.08	2.6	169	306	17.0	17.5	2.0	10.6	15.9	415	3.6	14.5	.6	0	1.0	8
17B	Ill-F-2	100	5.30	2.3	189	149	10.2	8.8	10.2	46.0	22.5	35.3	2.4	27.0	1.4	0	6.9	0
18	Ill-F-5	100	6.03	1.1	128	523	20.5	17.5	1.6	8.0	5.7	16.2	2.4	6.5	2.6	.3	4.1	.2
19	Ill-G-5	94.7	4.17	.8	13	409	33.7	11.9	1.6	6.0	7.5	11.1	2.0	4.9	2.8	1.2	3.3	2.4
20	Ill-H-5	100	3.22	.6	44	469	15.2	14.2	1.7	10.2	6.4	18.0	2.4	8.8	.6	0	3.3	3.1
21	Ill-S-5	25.3	8.39	1.1	35	743	45.8	22.6	3.6	25.4	20.0	0	2.5	6.5	1.2	1.8	5.0	7.8
22	Ill-Tr-5	57.1	7.57	1.9	126	329	13.3	16.8	1.7	5.6	9.8	10.9	2.2	12.4	2.2	.7	4.5	0
23	Ill-W-5	100	7.23	1.5	138	352	19.1	14.7	1.2	5.3	12.7	2.1	2.9	10.7	3.0	1.4	5.0	.4
24	Ill-B-2	100	5.57	4.3	168	193	19.9	8.0	4.0	16.2	24.7	2.9	3.6	23.8	.6	.3	9.0	.2
25	Ill-A-1	95.3	5.99	1.3	73	236	15.5	12.2	1.5	5.4	5.9	7.9	2.5	4.7	5.2	.6	7.1	1.3
26	Ill-P-1	100	5.96	3.1	76	276	28.8	17.9	4.8	18.1	10.7	130	4.4	18.7	5.3	.1	5.9	1.4
27	Ill-T-1	94.6	6.88	1.9	149	354	23.7	27.3	10.3	24.4	11.2	3.7	3.2	16.6	2.3	0	9.8	24.3
28A	Ill-S-DeK	62.3	7.67	2.2	43	377	29.7	22.1	2.4	7.2	7.6	14.3	3.4	9.0	3.6	.8	11.5	4.0
28B	Ill-S-Da	96.5	4.35	5.7	23	313	26.9	11.8	3.9	17.0	4.7	72	2.3	5.7	1.5	.1	12.7	19.4
29	Ill-P-Mu	100	4.07	1.6	44	330	17.0	8.7	1.5	6.7	5.9	2.2	1.9	.4	1.8	0	6.8	6.4
30	Ill-PH-LW	100	3.96	2.7	17	336	22.2	14.2	4.2	21.8	7.7	10.2	4.1	9.4	1.1	.2	8.0	7.7
31	Ind-L-VII	100	8.12	5.1	46	805	43	28.5	7.1	31.1	14	31.5	8	23.5	5.3	2.2	7.7	3.1
32	Ind-S-VI	80.1	7.40	4.0	112	814	23.2	21.1	4.8	28.3	10.9	5.6	5.7	15.6	.9	1.2	10.9	5.4
33	Ind-D-VI	58.1	4.52	1.4	65	228	12.7	10.4	1.4	6.7	10.8	1.8	1.9	.03	2.0	.12	4.7	6.0
34	Ind-P-V*	26.9	10.52	3.5	46	870	30.7	22.5	3.2	10.2	16.8	81.7	4.7	7	4.3	2.8	9.6	2.0
35	Ind-S-V	92.7	4.37	1.4	166	493	30.9	14.1	1.5	10.0	14.0	.4	2.7	5.5	7.8	1.5	6.0	3.5
36	Ind-C-III*	20.5	13.83	6.6	84	780	65	32	20.8	26.6	16.1	52.7	9.4	6.8	3.9	0	27.7	0
37	Ind-H-III	100	4.71	6.8	90	436	20.7	14.4	10.4	27.4	10.1	20.2	5.9	19.0	1.1	1.5	4.9	7.9
38	Ind-M-M	100	7.15	3.7	85	442	12.8	11.0	5.7	12.0	10.6	5	5	13.8	1.2	2.2	10.1	6.1
39	Ind-Hi-LB	50	8.83	4.7	85	1,240	33.2	26.5	18.8	8.4	19.7	38.4	6.3	13.9	.9	0	11.1	36.2
40	Ind-Ge	100	9.21	7.6	20	1,080	67.4	40.4	1.5	20.8	14.5	0	17.6	37.5	13.0	2.0	32.9	3.8
41	Ky-Co-14	100	3.96	2.4	167	379	26.6	25.9	4.7	25.2	13.3	5.7	3.8	3.0	3.0	21.9	13.4	5.0
42A	Ky-H-14	42.4	10.91	3.1	31	617	62.4	31.5	11.4	23.6	12.4	29.7	8.7	15.9	9.2	1.5	16.3	4.2
42B	Ky-H-11*	32.7	15.10	1.0	21	1,790	81.5	73	8.2	53.1	20.1	20.8	6.4	14	53.5	0	14.9	1.7
43A	Ky-Ho-12*	21.7	13.05	.5	40	738	35	39	16	23.9	20.4	110	8.3	4.4	6.6	0	11.3	9.1
43B	Ky-Ho-11*	14.7	8.44	1.6	93	416	32.5	19.1	4.4	15.8	13.5	3.9	6.0	18.7	15.9	0	9.8	2.9
44A	Ky-U-11	91.9	3.87	1.7	142	320	28.2	16.9	2.5	14	12.1	1.4	4.5	5.0	18	.6	5.8	2.1
44B	Ky-U-9	44.1	5.47	1.3	91	484	23.1	16.4	1.9	13.8	11.1	0	3.4	13.5	11.9	2.0	6.0	.9
45	Ky-BD-9		6.70	2.0	134	134	2.0	4.0	.6	2.7	3.4	13.4	.7	0	6.7	2.7	2.0	0
46	Ky-F-9	47.2	11.72	2.0	46	490	222	46.2	2.3	32	12.7	0	3.9	17.4	5.3	0	6.7	2.6
47A	Ky-G₁-9	58.5	8.95	3.6	42	1,400	41.9	46.4	6.0	18.6	9.6	18.3	5.2	13.3	4.6	.2	6.8	6.7
47B	Ky-G₂-9	36.9	6.49	2.3	174	478	21.6	19.5	2.9	27.3	13.6	11	4.2	39	3.2	1.4	6.1	10.9
48	Ky-OH-9		2.26	2.5	4.5	68	4.5	7.7	.9	6.6	2.3	9.0	11.3	11.8	2.7	4.5	13.6	4.5
49	Ky-PR-9	100	4.55	1.9	28.5	400	39	16.6	1.3	5.8	4.4	18.6	3.2	5.2	8.5	0	9.2	3.2
50	Ky-Sch-9*	34.6	10.78	4.4	48	670	27	30	5.4	21.4	12.1	62.8	5.2	24.4	.7	0	10.8	11.7
51	Ky-SP-9	100	7.51	2.5	24	830	182	53.5	4.6	10	6.6	18.3	4.1	9.6	11.7	5.0	5.8	6.6
	Ky-Wi-9	100	8.96	2.2	125	552	96.4	23	3.1	13.1	11.4	4.7	4.3	16.3	6.2	.8	9.3	9.8
	Ky-D-6	100	3.43	1.6	42	101	8.7	5.1	5.9	10.2	7.9	8.1	1.5	6.5	1.5	1.4	8.1	.4

WESTERN INTERIOR AND SOUTHWESTERN REGION

[All averages in parts per million. Averages calculated by using zero for element contents below limit of detection; averages in parentheses were calculated by using one-half of the detection limit of each element not detected. Location and description of samples given in table 1]

Locality (fig. 2)	Coal column	Ash (percent)	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Ia-P-M	12.32	1.9	150	220	13	12	14	66	34	+ 290 (300)	2.9	22	0.81 (.74)	0 (.52)	10	1.1 (2.6)
2 −	Ia-L-K	10.10	4.3	− 220	220	15	14	5	11	7.6	− 36 (39)	4.3 (4.4)	− 43	0 (.26)	0 (.5)	12	11 (12)
3	Mo-BN-B	8.01	3.1	78	200	16	9.6	3.8	14	10	13 (15)	3.9	8.2	2.2 (2.3)	.78	15	2.8 (3.3)
−	Mo-BS-B	5.41	2.6	100	220	13	13	3	13	14	5.4 (6.9)	4.2	24	3.8	0 (.37)	7.7	0 (1)
	Mo-B-Mu	7.09	3.4	110	310	+ 71	+ 61	6.6	23	22	8.4 (10)	2.6	11	+ 16	0 (.38)	12	0 (1.1)
4	Mo-P-T	16.72	.53	61	250	39	22	3	40	12	* 2,100	4.3 (4.4)	13	+ 12	0 (.84)	10	0 (2.5)
5	Mo-T-M	13.50	1.4	25	430	27	31	4.7	16	16	* 1,400	6 (6.1)	23	2.5	0 (.62)	10	5.7 (6.2)
6	OK-Pa-Fo	4	3.4	26	150	16	12	1.4	4.3	13	27	5.4	25	6.2	1 (1.1)	4.9	0 (.6)
	OK-Pa-BA	3.70	1.2	17	210	16	7	6.5	42	8.8	3.2 (4.6)	3	30	0 (.09)	.11 (.24)	3.7	.32 (.78)
7	OK-RC-BA	2.70	2.2	15	200	10	6.5	4.6	23	7.9	35	2.5	20	.24 (.27)	.24 (.35)	2.7	1.4 (1.5)
8	OK-MN-BA	3.29	2	37	310	12	7.8	7.9	22	7.5	26 (27)	2.5	23	2.4	.56 (.79)	3.3	1.4 (1.6)
9	OK-BH-H	2.60	1.6	42	180	11	8.7	3.9	10	6.3	17	2.1	17	5.1	.08 (.21)	3.4	1.2 (1.4)
10	OK-LC-So	4.23	1.4	20	300	22	16	.84	5.3	7.9	0 (8.5)	1	.88 (1)	5	1.7 (1.9)	6.1	7.5 (7.7)
11	OK-L-JO	3.15	.47	32	220	12	7.1	1.1	6.8	9	5.8 (10.3)	.82	.55 (.72)	3.8	1 (1.2)	5.2	3.6 (3.7)
12	OK-PC-Ca	3.75	.21	9.6	90	17	6.7	1.4	3.3	4.2	5.3 (11)	.25 (.3)	.21 (.48)	4	2.1 (2.2)	4	2.6
13	OK-SS-St	1.49	.22	2.5	160	7.7	5.3	6.4	8.9	7.4	4.8 (5.9)	.84	.30	1.9	.90	3.9	1.6
	OK-SS-StR	15.73	.04	22	1,100	44	28	1.6	7.9	16	0 (47)	3.6	0 (2.4)	4.2	0 (1.6)	13	31
14	OK-Gar-St	4.06	.33	4.1	140	26	8.4	1.8	8.9	7	8.5 (12)	1.2	0 (.40)	7.3	.51 (.75)	6.1	3.4 (3.7)
15	OK-Ca-St	3.06	.37	3.9	100	5.5	6.1	4.9	12	8.7	23 (26)	.82	0 (.31)	4.3	2.5 (2.6)	3.1	1.9 (2)
16	OK-Sa-Me	3.38	0.13	75	130	10	4.4	0.4	1.8	3.4	12 (15)	0.67	1.1 (1.3)	4.3	2.6	2.2	2.1 (2.2)
17	OK-Du-Me	3.66	.22	61	140	10	7.8	1.2	2.9	3.5	20	1	.79 (1.1)	3	5	3.8	2.5 (2.6)
18	OK-LS-Me	2.32	.11	8.5	70	9.6	5.3	3.2	8.7	4.6	16	.92	.62	3.6	1	1.7	1.5 (1.6)
19	OK-MA-Me	2.62	.19	37	140	16	8.2	1	4.8	4.5	14 (16)	.92	1.1	1.9	2	3.1	2.6
20	OK-K-UH	4.19	.28	50	67	4.7	11	9.3	15	8.5	2.8 (12)	.62	.11 (.30)	.58	1.1 (1.2)	2.6	.44 (1.7)
	OK-K-LH	8.45	.31	39	460	36	24	5.2	12	21	0 (20)	3.2	.60 (.90)	.70 (.72)	1.4 (2)	7.1	12
21	OK-LS-UH	2.70	.19	4.8	82	12	5.5	1.6	4.2	3.5	6.3 (7.1)	.59	.57	.86	.56 (.64)	2.8 (2.9)	2.2 (2.4)
	OK-LS-LH	2.54	.21	8	220	18	9.5	2.5	4.1	6.6	10 (11)	1.2	.24 (.35)	5.1	.81 (.86)	4	2.6 (2.8)
22	OK-EC$_2$-LH	3.59	.79	7.9	790	50	36	6.1	14	29	18	3.6	1.1	.97	2.2	+ 35	6.1
	OK-EC$_1$-UH	1.64	.11	2.9	61	8.6	5.1	1.1	1.7	3.1	12	.42	.88	.60	1.9	2.1	2
	OK-EC$_2$-UH	1.87	.08	3.5	61	8.8	4.7	.85	1.1	2.9	10	.45	.65	.67	2.2	2.1	2.8
23	OK-Da-UH	2.98	.36	5.3	200	15	6.7	5.7	10	6.2	5.6 (8.5)	.84	0 (.30)	1.4	1.4 (1.6)	4.4	2.6
24	Ark-NS-P	6	.24	12	160	22	11	4.1	8.7	14	17 (23)	1.3	0 (.75)	3.6	2 (2.4)	4.6	4.7 (4.9)
25	Ark-Ha$_{19}$-Ch	11.59	.83	6.7	180	23	8.2	8.3	16	24	0 (36)	3.1	4.5	3.1 (3.4)	2.5 (3.3)	15	16
	Ark-Ha$_{11}$-Ch	3.74	.52	10	220	14	10	13	17	7.5	0 (11)	1.5	0 (.57)	1.5	0 (.37)	9.4	20
26	Ark-Ha$_{13}$-Ch	5.67	.15	3.1	150	12	7.5	3.3	12	5.4	83 (84)	1.3	0 (67)	2.7	0 (.48)	3.4	5.4 (6.7)
27	Ark-Sk-Ch	4.67	.74	7.8	220	14	13	16	20	7.5	32	1.7	0 (.24)	2.5	0 (.24)	13	17
28	Ark-QE-UH	6.64	.04 (.10)	17	220	8.7	10	1.7	7.4	6.7	0 (20)	1.2	0 (1)	2	1 (1.5)	2.6	4.6 (5.1)
29	Ark-Ba-LH	7.65	.43	14	380	23	18	3	15	9.2	21 (39)	2.4	0 (1.2)	1.8	.16 (.85)	7.5	8.7
30	Ark-Hu-LH	6.07	.38	16	200	24	18	2.8	19	14	50	2.2	0 (.75)	1.8	0 (.55)	7.2	9
31	Ark-Ha$_{18}$-LH	3.42	.20	15	150	9.2	8.9	4.4	15	12	47 (50)	.90	0 (.52)	4.8	0 (.34)	2.4	3.5
32	Ark-OZ-LH *	12.23	4.5	6.1	290	12	16	3.7	34	37	0 (31)	1.1	0 (.61)	.49	0 (1.2)	20	25
33	Ark-ACM-LH	3.95	.34	20	240	8.3	7.7	7.4	10	9.3	0 (9.7)	1.2	0 (.19)	1.1	0 (.39)	4.9	7.3
	Ark-ACM-LHR	5.79	.36	13	150	8.1	8	3	5.6	25	0 (12)	.86	0 (.74)	1.4	1.7 (1.6)	3.9	0 (1.8)
34	Ark-PV-LH	10.51	3.4	30	660	17	17	15	47	26	0 (26)	2.3	0 (.55)	1.7	0 (1.1)	16	22
35	Ark-EJ-LH	12.19	5.5	11	350	23	31	3.9	22	24	0 (30)	1.2	0 (.61)	.73	2.4	27	37
36	Ark-Ru-LH *	41.70	* 11.3	120	2,500	* 130	* 80	* 44	* 250	* 83	0 (104)	* 16	0 (2.1)	5.1	0 (4.2)	* 37	* 79
37	Ark-Dr$_1$-At *	24.5	* 13	20	1,200	44	42	7.1	* 69	* 74	0 (61)	5.4	0 (1.2)	2	0 (2.4)	* 93	* 59
	Ark-Dr$_2$-At *	47.3	* 22	43	2,800	* 95	* 120	6.2	27	* 95	0 (120)	* 14	0 (2.4)	6.2	0 (4.7)	* 290	* 210
38	Ark-M-UE	12.90	7.1	67	3,200	31	18	5.5	14	25	0 (34)	7.3	3 (3.7)	1	.91 (1.7)	+ 43	+ 84
	Ark-M-LE	13.27	5.1	60	3,100	+ 60	38	6.9	22	19	+ 230 (370)	+ 19	+ 45	1.4	2.3 (2.5)	20	34
39[1]	Tex-Mc-UE	8.86	.18 (.22)	180	940	19	9	1.4	4.4	13	0 (29)	3.3	0 (1.5)	.97	0 (.95)	6.2	0 (3.5)
	Tex-Mc-LE	9.80	.32 (.36)	160	720	13	6.4	1.4	5.4	14	0 (26)	2.7	0 (1.3)	.79	0 (.87)	5	9.6 (3.5)

[1] South of area shown in figure 2.

* Weathered samples, not included in averages.

Summary Table XI appears in three sections on successive pages, following the three groups of elements listed above in Table IV. The elements listed in each section are in the order of increasing atomic weight. The first page of the table includes elements named by EPA or commonly elsewhere in the literature as hazardous air pollutants. The second two pages include additional elements for which data are available on a coal basis, from the USGS surveys. The last page includes a third list of elements for which the USBM survey data are available on an ash basis only.

Data for each element are presented separately for the 5 major producing regions: Appalachian (A), Interior-Eastern (IE), Interior-Western (IW), Western (W), and Northern Plains (N). The states included in each of these regions are given above in Table III. Averages and ranges reported for each region are kept on the same line across the table. In some cases where the Southwest Energy Study appears to give a broader data base than the W ranges, based on more samples, SW data have been reported instead of W in the table.

The "variance" ratio is given for each element with its symbol in the first column. This is the ratio of the highest to lowest average of analyses for areas within the region. The averages for area within the region are given in the second column as reported by Zubovic, or calculated for the same areas by states from other data for fluorine and mercury.

The next column gives ranges for the analysis of the coal beds within each region which include 90+% of the values reported, for columnar samples as discussed above. Coal blocks which were either included or excluded in the averages reported in the first half of the USGS survey are excluded here when they represent less than 75% of a columnar sample. These samples are ticked off in the "Percentage of bed analyzed" column of the original data, as copied in Table XII.

The extreme values not included in the 90+% range are listed separately, or as a range. Their occurrence is given in parentheses as a ratio to the number of bed samples considered here, including the extremes, after casting out values where only selected blocks were analyzed. This is correspondingly less than the total number of beds in the original report, which are the basis for the USGS averages given here by areas within the regions. These averages by area would be affected somewhat by recalculation to omit the extremes, but usually to only a minor extent. Where no extremes are listed the 90+% range is actually 100%: the value which 90+% represents is 100% less the occurrence of the extremes.

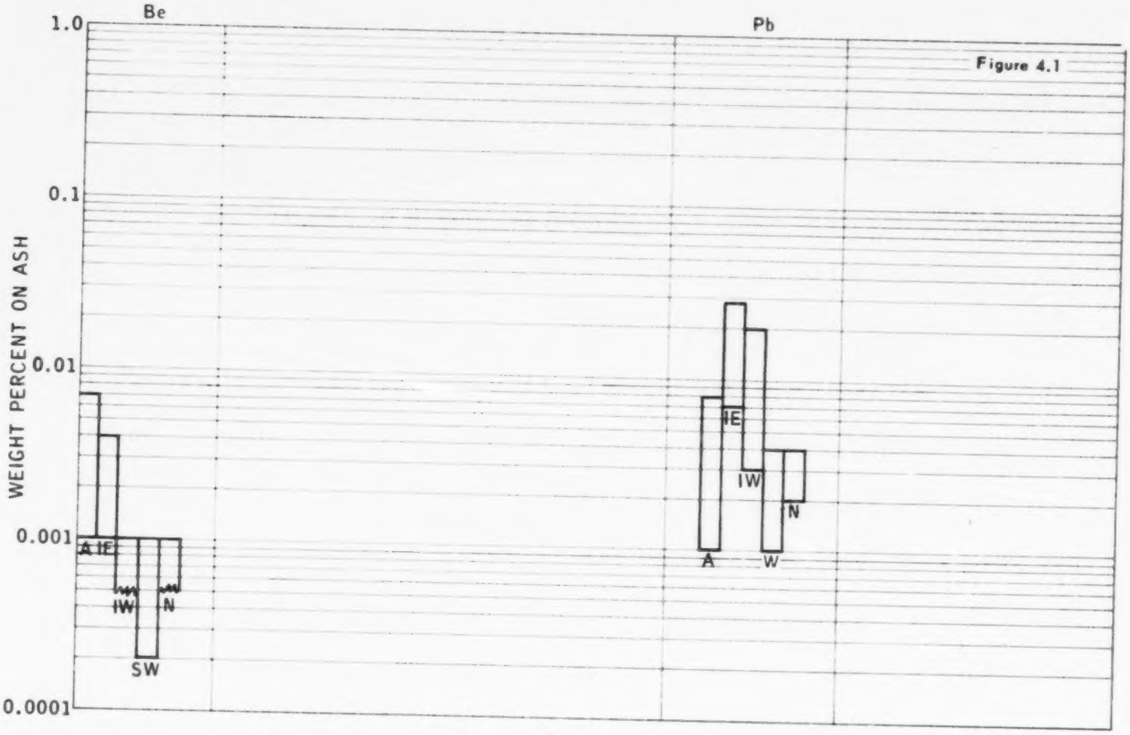
The ranges given for ash values for coals from the same 5 regions are taken basically from the USBM data which Abernethy reports as averages by states(4).

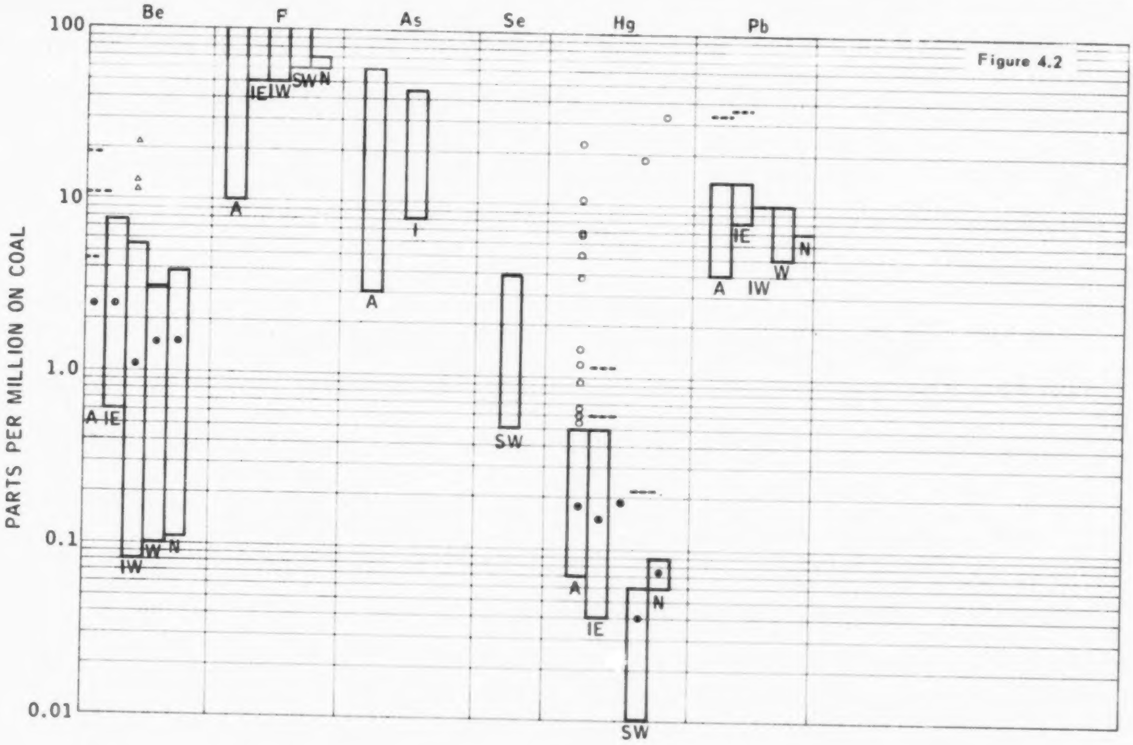
The comments given for each element are directed primarily to geographical correlations between composition and location of the coal. These comments based on the present summary are taken in part from Zubovic(12) and Abernethy(13), with additions from the recent literature, after checking directly with Zubovic and Swanson of the USGS and Schultz of USBM. The comments refer to all regions, except for uranium where separate comments are given by region. References are given herein for each element where data or comments were taken from special sources.

The data summarized in Table XI are presented in Figure 4 as bar graphs for each element, by regions. The USBM data for ppm on ash are shown at the top, and the USGS data on a coal basis at the bottom. The bar graphs for coal are the 90+% ranges, the dotted lines (---) are the extremes listed, and the regional average (●) is for the total region as given by USGS. This average is usually near the middle of the bar but it moves toward the top of the bar or may exceed it when there are many extremes, as for vanadium or zinc. Ranges which start below the limit of detection are shown by a 0 in Table XI and a broken bar line below 1 ppm in Figure 4. Shorter dotted lines (--) represent values outside the 90+% range which were included in the USGS average but excluded here because they were for beds less than 75% analyzed. The high specimen sample values for mercury reported by Joenssuu are indicated by a O, and Δ shows the high values for weathered samples, not included in the averages.

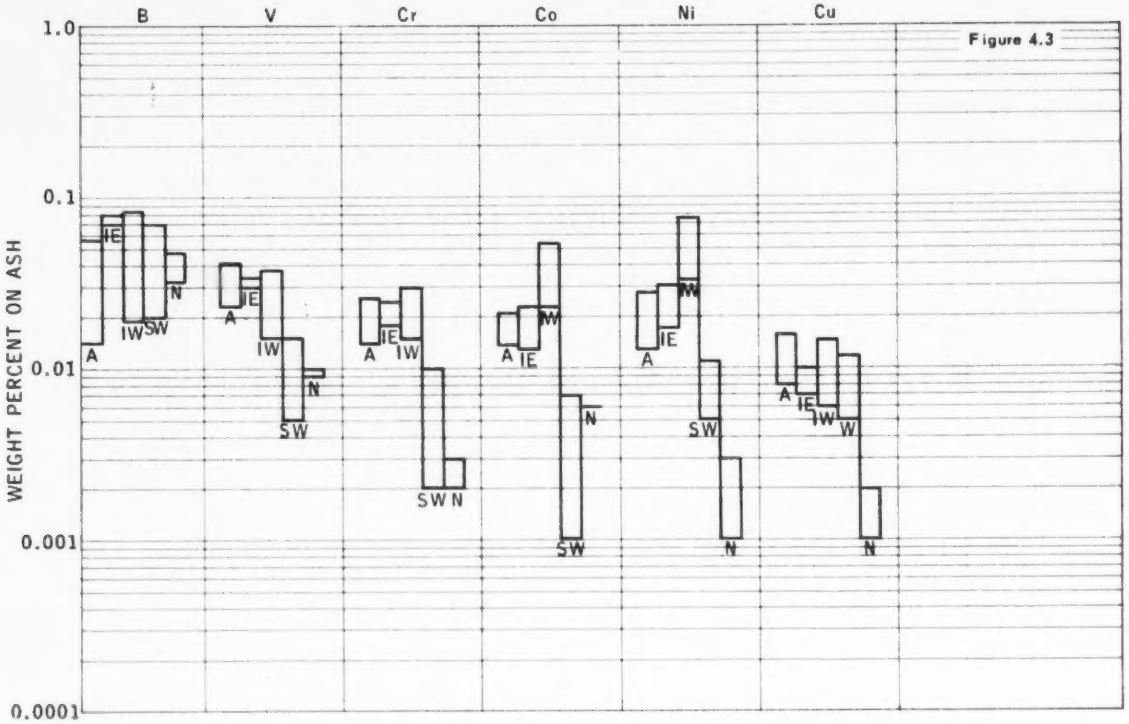
The bar graphs for most elements, thus adjusted, lie within the range of 1 to 50 ppm, and mostly close to 5-10 ppm on coal. The only elements significantly higher than this are boron and fluorine, in the range from 10 to 200 ppm. Beryllium is lower in all regions by an order of magnitude, at about .1 to 5 ppm, and Hg by two orders of magnitude, at about .01 to .5 ppm on coal.

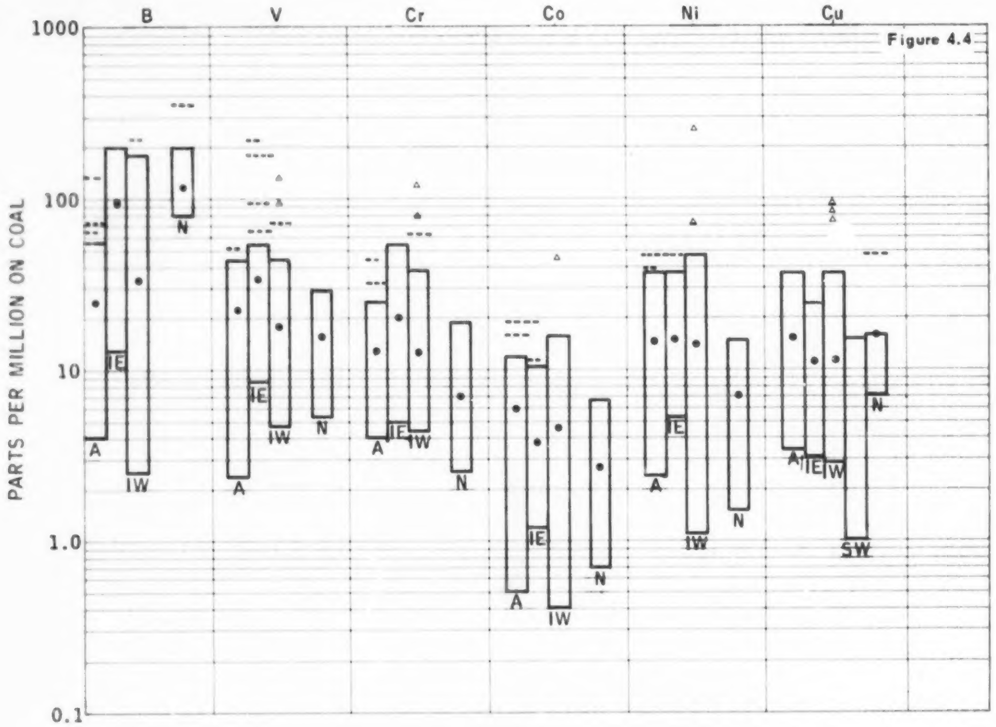
TRACE ELEMENTS IN U.S. COALS





TRACE ELEMENTS IN U.S. COALS





TRACE ELEMENTS IN U.S. COALS

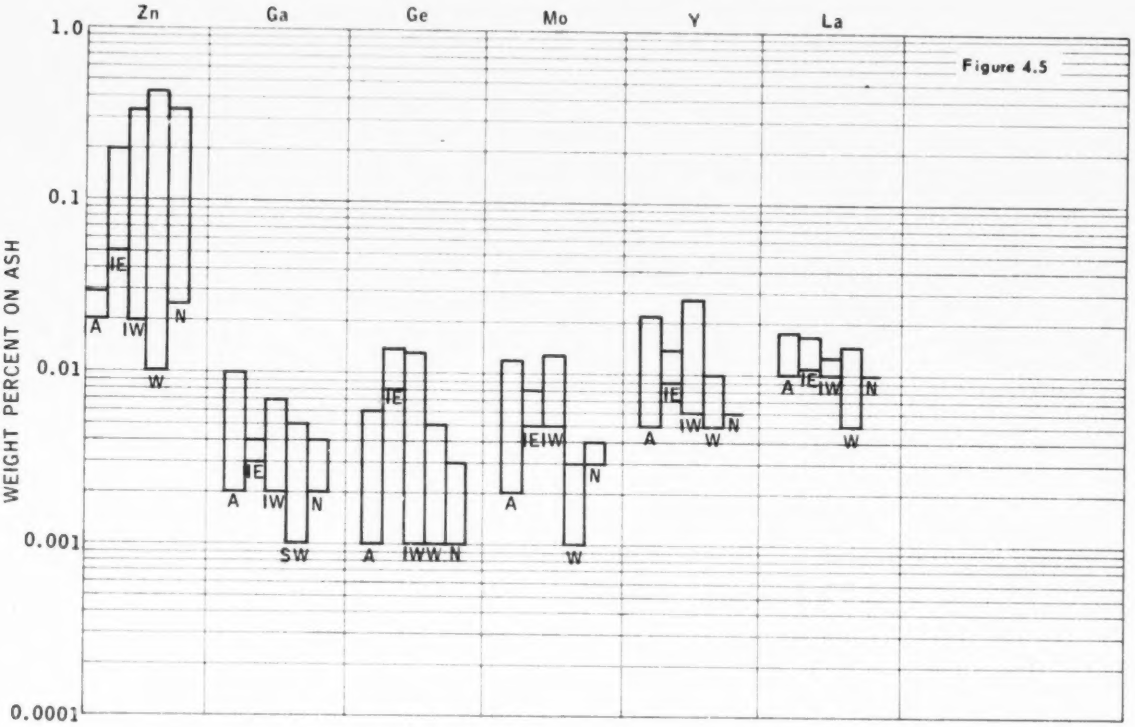


Figure 4.5

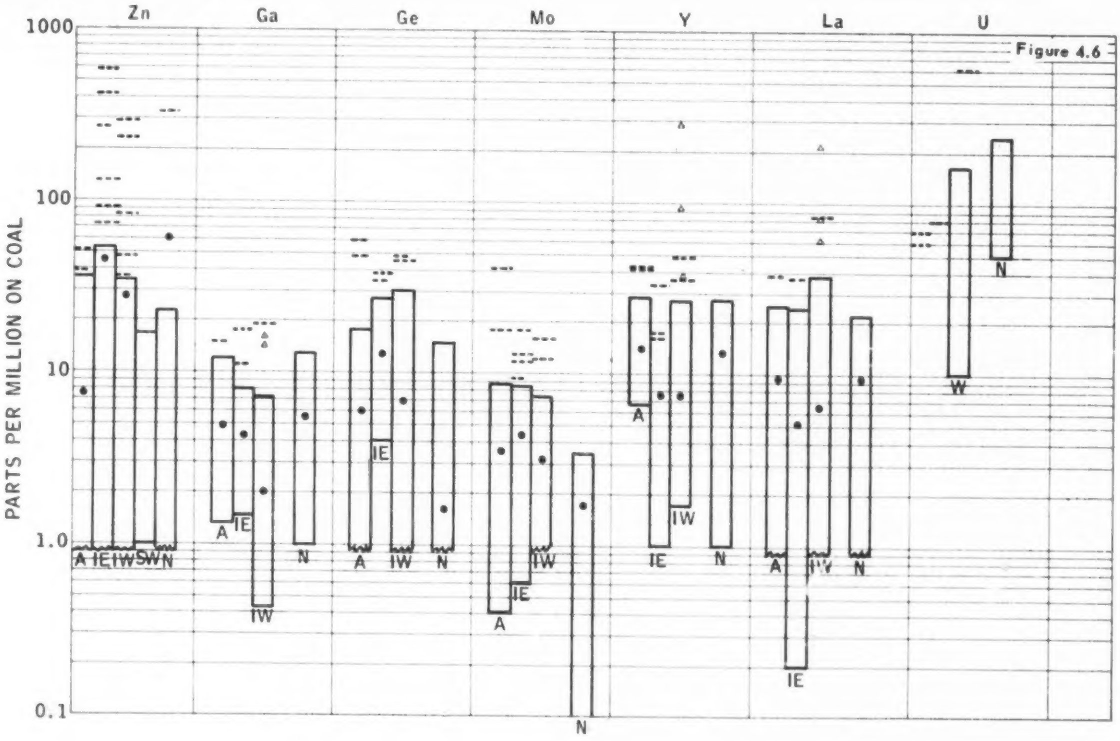


Figure 4.6

TRACE ELEMENTS IN U.S. COALS

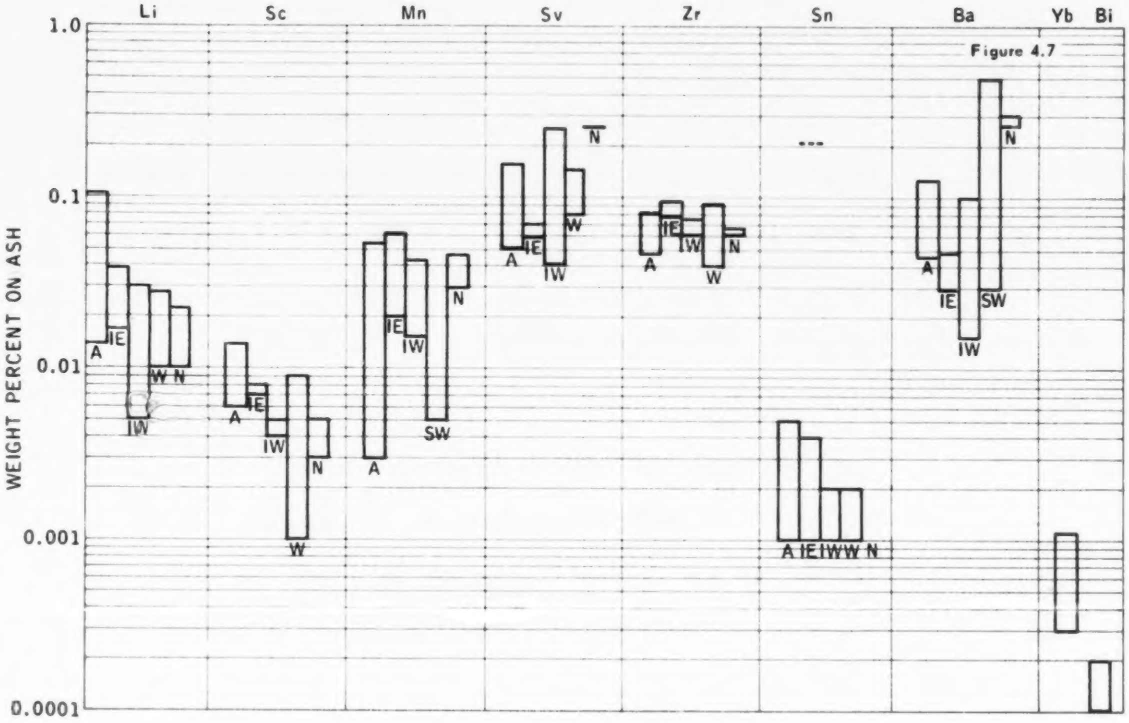


Figure 4.7

4. Concluding Remarks

4.1 Correlations Indicated

1. Sulfur in coals appears in moderate amounts in the Appalachian region, higher in the Interior region (East and West), and less in all the Western coals.
2. Trace element concentration as a whole correlates only moderately with geographical location, and not at all with coal rank. Boron, which is high in lignites and lower in high rank coals, is an exception.
3. The amount of some trace elements is commonly highest in the top and bottom few inches of a bed, and at the edges of a coal basin (Ge, Be, Ga, and B at bottom only). These variations are frequently greater than the differences between the averages for different beds. Other elements (Cu, Ni, Co) show no such correlation.
4. Different elements tend to be concentrated at different parts of the bed or basin, depending on the geochemical processes involved in the formation of the coal.
5. Those elements which tend to be concentrated in coals (S, Ge, Be, B, Ga) are associated primarily with the organic portion of the coal. They also show the largest variance in average concentrations between different major producing areas: e.g., for germanium, which is high in Illinois.
6. The usual amount of some 20 trace elements present is about 5-10 ppm, in the range 1-50 ppm. B and F are higher, about 10-200 ppm, and Hg is lower, about .04-.4 ppm.

7. Most trace elements are present in concentrations which fall within a narrow range, varying by a factor of 3 or less in the averages for different basins or areas. This range is close to their average crustal abundance, which usually lies between the concentration of the element in coal and its concentration in ash. Boron and germanium in coal are high, compared to crystal abundance and only a few elements such as manganese are low.
8. The selection of a completely "non-polluting" coal is not possible, in the general case. For a given amount of ash, coals which are low in any one group of elements must be correspondingly high in others. The definition of non-polluting depends directly on the decision as to which elements are of concern, and which are not.
9. Trace element variations between coals in different areas often reflect differences in the source rocks which contributed the elements to the coal-forming swamps, and the distance of the source rocks from the swamp. In certain areas, e.g., the Illinois basin, this shows an instructive geographical pattern.
10. Surface outcrops or samples weathered otherwise by exposure may not be indicative of trace element concentrations in the coal at depth. Surface oxidation creates active sites on the coal, with which minor elements in flowing water can selectively react.

11. The elements present in largest amount, as minor components of the coal rather than as traces only, are the common constitutents of surface waters and rocks: silicon, aluminum, iron, sulfur, phosphorus, sodium, potassium, calcium, and magnesium. These are present throughout the coal but they are often enriched in the top layer, where they have apparently been leached out of enclosing sediments.

12. Anomalous amounts of specific elements may be found in beds contiguous to mineral ore bodies of the same element. This is regularly the case for coals having a mercury, lead, zinc or uranium content higher than the usual range, and may be equally true for other elements including copper, tin and arsenic.

4.2 New Data Required

1. Little or no data were obtained in the comprehensive USGS and USBM field reviews on the content of the hazardous elements F, As, Se, Cd and Hg, in typical U.S. coals. This lack has been partially filled for mercury by recent studies, and it is being found in quantities much lower than those commonly quoted in the literature. Results for the other toxic elements noted are spotty at best, and methods for As, Se and Cd are still in the research stage.
2. Reliable data are needed and not yet available on coals representing large future reserves which are not yet in production, such as those in Wyoming. These data should be on a basis which is directly comparable with the data for other regions. This means that they should either be obtained using the previous standard methods of analysis, or if newer methods are used after sufficient evaluation, they must be applied to a complete set of both old and new samples.
3. Changes have been noted in some stored samples on re-analysis by the original standard procedures, so it is not enough to re-examine old samples by a new method. The situation to be particularly avoided is analyzing the newer samples only by a new method of analysis, which is not tied in any way into the present bank of basic data.

4. There is a similar need for basic data on the effects of coal conversions on the fate of trace elements, including the effect of operating conditions on the distribution of elements between fly ash (overhead) and bottom ash in combustion, in gasification, and in all other forms of processing. For these studies it is not as important to tie newer methods of analysis to older results. The method must be calibrated well enough within the range of concentrations and interferences concerned to be sure that it gives differential results which are reliable.

5. Major differences exist in the physical and chemical properties of the forms in which potentially pollutant elements are emitted on combustion. This includes such questions as the ionic state of fluorine, the oxidation state of beryllium, the formation of spinels from oxides, and the physical/chemical effects of the surfaces of sub-micron particles. In each of these cases one form may be metabolically active, and another in equal amounts inactive. These effects will require special attention if the list of toxic hazards is extended to include elements whose presence in minute traces is recognized as essential to health.

C. PETROLEUM

1. Background

The nonhydrocarbon elements present in crude oils in trace quantities can be introduced into the environment as a consequence of the consumption of crude oil. These elements which have been entrapped beneath the earth's surface for eons may produce ecological damage when the crude oil is processed and/or as the crude oil products are consumed.

In general, the source of petroleum is believed to be the remains of marine animal and vegetable life deposited with sediment in coastal waters(21,22). Bacterial action evolves sulfur, oxygen and nitrogen as volatile compounds. These, however, are never completely eliminated despite the ever increasing pressure of sediment. The result of this process is a mixture of hydrocarbons containing varying quantities of sulfur, nitrogen and traces of metals and other elements. The properties of this mixture depend on the nature of the source material and the subsequent influential forces which include time, temperature, geological factors and catalysts. Because these parameters vary from one geological location to another, a wide variety of crude oil compositions result.

Unlike coal, virtually all oil is subjected to extensive processing during which the oil is converted into usable products. The categories of processing include fractionation (distillation of crude into different cuts), converting (chemically transforming cuts into products) and treating (removal of unwanted components). Much of the pollution associated with refining can be attributed directly to the presence of trace elements in crude oil. These trace elements can be released during all processing categories, especially the latter two. Those trace elements which are not removed from oil during processing end up in the usable products. Because most products are fuels, the trace elements can be released into the environment as pollutants when the fuels are combusted.

Of the trace elements present in crude oil, sulfur and nitrogen are generally present at the highest levels. Sulfur in commercial crude oils can be found in concentrations up to 6% while nitrogen can occur up to 1%. Because these two elements are present at such high levels relative to the other trace elements in crude oil, sulfur and nitrogen may be considered to be minor constituents of the crude. More than 40 other elements can be present in crude oils at trace levels (21) but only a limited number of these elements have been regarded as potential environmental pollutants or health hazards. This work presents a collection of published data for the minor constituents and those trace elements in crude oil regarded as potential environmental and/or health hazards. The elements considered here are listed below.

minor constituents: sulfur, nitrogen
trace elements: vanadium, nickel, iron, arsenic, beryllium,
cadmium, mercury, selenium,antimony, barium,
chromium, lead, manganese, molybdenum
tellurium, tin.

Data presenting the levels of minor constituents and trace elements present in crude oils vary widely in both quantity and quality. Data for sulfur and nitrogen are widely available and are usually of high quality if ordinary laboratory care has been taken in performing the analyses. Considerable sulfur and nitrogen data from U.S. crudes and some foreign oils are available from the U.S. Bureau of Mines. Sulfur and nitrogen determinations are now a part of the BuMines' routine procedure for the analysis of crude oils. The sulfur determination has been part of this analysis for many years but measurements for nitrogen began during the early 1960s. Because of this, nitrogen data are somewhat less abundant than sulfur data.

Much less work has been done in determining the levels of other trace elements in crude oils. One reason for this is that the trace element concentration of commercial crude oils is low. In the past, these low levels have been regarded as inconsequential except to the extent that a few of these elements have adversely affected refinery processing. Additionally, techniques and instrumentation generally have not been available to determine the very low levels of trace elements present in petroleum. When trace element analyses of petroleum have been attempted, results have sometimes been inconsistent. There are many possible reasons for this, ranging from improper sampling and accidental sample contamination to poor sample pretreatment and analytical technique.

Both vanadium and nickel poison petroleum cracking and other catalysts. When present in high concentrations in residual fuels, vanadium can cause damage to equipment in turbines and other high temperature equipment. Consequently, there has been considerable impetus on the part of each petroleum company to know the vanadium and nickel levels of crudes which it processes. Most of this information is retained by these companies as private although a limited amount has been published. Other trace elements have been determined much less frequently.

The validity of some of the data which are currently available has been questioned by authorities. In certain cases, this may be due to the intrinsic limitations of the technique utilized in the measurement of certain elements or certain concentrations, or, these inconsistencies may be attributed to the sampling and technique errors noted previously. Several programs are under way to establish referee methods which can aid in overcoming these objections. The American Petroleum Institute is sponsoring Project SS-7 to determine if the neutron activation analysis technique used at Intelcom Rad Tech is sufficiently accurate to serve as a standard method for determining trace elements in petroleum and petroleum products. In addition, an inter-company program within the petroleum industry is underway to develop referee methods for analyzing petroleum associated trace elements down to the parts per billion level. Consequently, while the quantity of reliable trace element data on crude oils is strictly limited at present, it can be expected that either or both of these programs will establish analytical techniques from which reliable petroleum trace element data will be more readily obtainable in the future.

The following sections present crude oil trace element data for U.S. oil fields and for crudes from nations which export oil to the U.S. Data obtained using activation analysis are presented in a separate section. Data for shale oil which has potential as an energy source in the 1980's are included in a subsequent section. This is followed by a summary of the findings of this study and recommendations for future work.

2. Domestic Crude Oils

Of the total amount of crude oil processed in the United States, approximately 85% is produced domestically with the balance being imported(23). Approximately two-thirds of domestic crude oil production is obtained from a relatively small number of large oil fields, sometimes termed "giant" fields.* Generally, U.S. giant fields are defined as those possessing reserves in excess of 100,000,000 bbl. (Some of the older fields which have been in continual production may now possess reserves less than this level. Additionally, certain large new fields may presently be shut in or in a state of development thereby accounting for their relatively low production). These large oil fields are responsible for a majority of U.S. oil production and they are also representative of the nation's total oil production. This occurs because many smaller oil fields in close proximity to the giant fields possess very similar characteristics including similar trace element concentrations. In practice, the production of these smaller fields is generally combined with that from the large fields in the pipe line networks that grid oil producing regions. Thus, the oil arriving at refineries is a mixture, dominated by production of the giant fields. Consequently, for practical purposes, the characteristics of the larger fields characterize the great bulk of all domestic petroleum production.

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* "Giant fields" is a relative term. Of the current producers, the two largest are the Wilmington (California) and East Texas fields. Each produces approximately 70-75 thousand barrels per day. This may be contrasted with the Ghawar field in Saudi Arabia, the world's largest, which has a production level more than ten fold greater than Wilmington. Reserves of the Ghawar field are estimated to approach 70 billion barrels.

2.1 Sulfur and Nitrogen Data

Because of the prominence of the giant fields, their crudes have been the subject of much of the trace element data that are available. Sulfur and nitrogen data for crude oils from these fields are the most complete and consequently will be considered separately. Of a total of 259 giant U.S. oil fields, sulfur data were obtained for 251 fields (96.9%) and nitrogen data were acquired for 229 fields (88.4%). On a production basis, sulfur data covered 94.6% of giant field's production, and the nitrogen data 88.5%. Most of the sulfur and nitrogen data were obtained from Bureau of Mines sources through either publications or open files of crude oil analyses.

In assembling this compilation, data from published, widely available sources were utilized in preference to data from less available sources. Consequently, published Bureau of Mines data took precedence over Bureau of Mines open file analysis data. An average was obtained when duplicate BuMines data were available for a given field. Data officially published by the Bureau were used in preference to those appearing elsewhere, even if the authors of these other works were Bureau personnel. The giant field sulfur and nitrogen data follow in Table 13.

TABLE 13

SULFUR AND NITROGEN CONTENT OF THE GIANT U.S. OIL FIELDS

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References**	
				Sulfur	Nitrogen
ALABAMA					
Citronelle	0.38	0.02	6,390		
ALASKA					
Granite Point	0.02	0.039	5,552	25	25
McArthur River	0.16	0.160	40,683	26	25
Middle Ground Shoal	0.05	0.119	11,277	25	25
Prudhoe Bay (North Slope)	1.07	0.23	1,076	26	26
Swanson River	0.16	0.203	11,709		
APPALACHIAN					
Allegany	0.12	0.028	388		
Bradford	0.11	0.010	2,470		
ARKANSAS					
Magnolia	0.90	0.02	850		
Schuler and East	1.55	0.112	800		25
Smackover	2.10	0.08	2,800		
CALIFORNIA					
SAN JOAQUIN VALLEY					
Belridge South	0.23	0.773	9,211		
Buena Vista	0.59	--	5,429		
Coalinga	0.43	0.303	7,866		
Coalinga Nose	0.25	0.194	4,752		
Coles Levee North	0.39	0.309	1,006		
Cuyama South	0.42	0.337	2,034		
Cymric	1.16	0.63	3,345		
Edison	0.20	0.446	1,417		
Elk Hills	0.68	0.472	951		
Fruitvale	0.93	0.527	1,109		
Greeley	0.31	0.266	761		
Kern Front	0.85	0.676	3,440		
Kern River	1.19	0.604	25,542		
Kettleman North Dome	0.40	0.212	840		
Lost Hills	0.33	0.094	2,328		
McKittrick - Main Area	0.96	0.67	5,348		
Midway Sunset	0.94	0.42	33,583		26
Mount Poso	0.68	0.475	1,378		
Rio Bravo	0.35	0.158	425		
COASTAL AREA					
Carpenteria Offshore	--	--	5,295		
Cat Canyon West	5.07	0.54	2,705		26
Dos Cuadras	--	--	27,739		
Elwood	--	--	108		

* Oil and Gas Journal, January 31, 1972 pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

TABLE 13 (Cont'd)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References**	
				Sulfur	Nitrogen
Orcutt	2.48	0.525	2,173		
Rincon	0.40	0.48	4,580		
San Ardo	2.25	0.913	9,939		
Santa Ynez***	--	--	--		
Santa Maria Valley	4.99	0.56	1,966		26
South Mountain	2.79	--	1,962		
Ventura	0.94	0.413	10,188		
LOS ANGELES BASIN					
Beverly Hills	2.45	0.612	8,400	25	25
Brea Olinda	0.75	0.525	4,228		
Coyote East	0.95	0.336	864		
Coyote West	0.82	0.347	2,436		
Dominguez	0.40	0.360	1,717		
Huntington Beach	1.57	0.648	16,249		
Inglewood	2.50	0.640	3,992		
Long Beach	1.29	0.55	3,183		
Montebello	0.68	0.316	740		
Richfield	1.86	0.575	1,910		
Santa Fe Springs	0.33	0.271	953		
Seal Beach	0.55	0.394	1,468		
Torrance	1.84	0.555	1,338		
Wilmington	1.44	0.65	72,859		26
COLORADO					
Rangely	0.56	0.073	10,040		
FLORIDA					
Jay	0.32	0.002	370	26	26
ILLINOIS					
Clay City	0.19	0.082	4,650		
Dale	0.15	0.080	690		
Loudon	0.27	0.097	4,420		25
New Harmony	0.23	0.158	2,740		
Salem	0.17	0.102	3,360		
KANSAS					
Bemis-Shutts	0.57	0.162	2,590		
Chase-Silica	0.44	0.13	1,600		
Eldorado	0.18	0.085	1,500		
Hall-Gurney	0.34	0.108	2,480		
Kraft-Prusa	0.27	0.171	3,200		25
Trapp	0.41	0.076	1,930		25
LOUISIANA					
NORTH					
Black Lake	--	--	--		
Caddo-Pine Island	0.37	0.026	3,500		25
Delhi	0.82	0.053	5,870		
Haynesville (Ark.-La.)	0.66	0.022	2,730		25
Homer	0.83	0.081	330	25	25
Lake St. John	0.17	--	1,170		
Rodessa (La.-Tex.)	0.46	0.032	900	25	25

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

*** Undeveloped field, Santa Barbara Channel. Uncorroborated estimate of reserves of 1 to 3 billion bbl.

TABLE 13 (Cont'd.)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References** Sulfur	References** Nitrogen
OFFSHORE					
Bay Marchand Block 2 (Incl. onshore)	0.46	0.11	30,806		26
Eugene Island Block 126	0.15	0.030	5,621		
Grand Isle Block 16	0.18	0.04	21,681		
Grand Isle Block 43	--	--	22,776		
Grand Isle Block 47	0.23	0.04	4,271		
Main Pass Block 35	0.19	0.071	3,504		
Main Pass Block 41	0.16	0.025	18,469	25	25
Main Pass Block 69	0.25	0.098	12,775		
Ship Shoal Block 208	0.38	0.02	10,038	26	26
South Pass Block 24 (Incl. onshore)	0.26	0.068	20,330		
South Pass Block 27	0.18	0.049	21,425		
Timbalier S. Block 135	0.66	0.088	13,578	25	25
Timbalier Bay	--	--			
(Incl. onshore)	0.33	0.081	30,988		
West Delta Block 30	0.33	0.09	26,390		
West Delta Block 73	--	--	15,987		
SOUTH, ONSHORE					
Avery Island	0.12	--	3,400		
Bay De Chene	0.27	0.060	6,643		
Bay St. Elaine	0.39	0.04	7,775		
Bayou Sale	0.16	--	5,293		
Black Bay West	0.19	0.04	9,892		
Caillou Island (Incl. offshore)	0.23	0.04	31,828		
Cote Blanche Bay West	0.16	0.033	15,658		
Cote Blanche Island	0.10	0.01	8,797		
Delta Farms	0.26	0.055	1,278		27
Garden Island Bay	0.22	0.06	16,096		
Golden Meadow	0.18	--	2,738		
Grand Bay	0.31	--	6,680		
Hackberry East	0.30	0.054	2,226		
Hackberry West	0.29	--	3,760		
Iowa	0.20	0.039	876		
Jennings	0.26	--	292	25	
Lafitte	0.30	--	10,877		
Lake Barre	0.14	0.02	7,592		
Lake Pelto	0.21	0.035	4,891		
Lake Salvador	0.14	0.02	4,380		
Lake Washington (Incl. offshore)	0.37	0.146	10,913		
Leeville	0.20	0.019	4,343		
Paradis	0.23	--	1,898		
Quarantine Bay	0.27	0.061	7,117		
Romere Pass	0.30	--	3,759		
Venice	0.24	--	5,475		
Vinton	0.34	0.044	2,299		25
Weeks Island	0.19	--	10,183		
West Bay	0.27	0.071	9,563		

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

TABLE 13 (Cont'd.)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Product (Thousands of Barrels)*	References** Sulfur	References** Nitrogen
MISSISSIPPI					
Baxterville	2.71	0.111	9,300		
Heidelberg	3.75	0.112	3,450		
Tinsley	1.02	0.08	2,450		
MONTANA					
Bell Creek	0.24	0.13	5,950	26	26
Cut Bank	0.80	0.055	5,180		
NEW MEXICO					
Caprock and East	0.17	0.034	905		
Denton	0.17	0.014	2,350		
Empire Abo	0.27	0.014	9,520		
Eunice	1.14	0.071	1,330		
Hobbs	1.41	0.08	5,700		
Maljamar	0.55	0.062	6,040		
Monument	1.14	0.071	3,720	25	25
Vacuum	0.95	0.075	17,030		
NORTH DAKOTA					
Beaver Lodge	0.24	0.019	3,140		
Tioga	0.31	0.016	1,790		
OKLAHOMA					
Allen	0.70	0.21	2,920		
Avant	0.18	--	365	25	
Bowlegs	0.24	0.140	2,260	25	25
Burbank	0.24	0.051	5,240		
Cement	0.47	0.152	2,370		
Cushing	0.22	0.08	4,300		
Earlsboro	0.47	--	765	25	
Edmond West	0.21	0.045	730		
Eola-Robberson	0.35	0.115	4,850		
Fitts	0.27	--	1,420	25	
Glenn Pool	0.31	0.096	2,480		
Golden Trend	0.15	0.15	12,330		
Healdton	0.92	0.15	4,600		25
Hewitt	0.65	0.148	5,660		
Little River	0.28	0.065	440	25	25
Oklahoma City	0.16	0.079	1,750		
Seminole, Greater	0.30	0.016	1,640	25	25
Sho-Vel-Tum	1.18	0.27	36,500		
Sooner Trend	--	--	15,240		
St. Louis	0.11	0.04	1,350		
Tonkawa	0.16	0.033	290	25	25

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

TABLE 13 (Cont'd.)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References** Sulfur	References** Nitrogen
TEXAS					
DISTRICT 1					
Big Wells	--	--	5,840		
Darst Creek	0.78	0.075	1,971		
Luling-Branyon	0.86	0.110	1,679		
DISTRICT 2					
Greta	0.17	0.038	3,577		
Refugio	0.11	0.027	657		
Tom O'Connor	0.17	0.038	23,360		
West Ranch	0.14	0.029	17,009		
DISTRICT 3					
Anahuac	0.23	0.041	9,052		
Barbers Hill	0.27	0.06	766		
Conroe	0.15	0.022	12,994		25
Dickison-Gillock	0.82	0.014	2,920	25	25
Goose Creek and East	0.13	0.028	1,095		
Hastings E&W	0.20	0.03	17,191		
High Island	0.26	0.048	2,081		
Hull-Merchant	0.35	0.081	1,643	28	28
Humble	0.46	0.097	1,241	28	28
Liberty South	0.14	0.044	949		
Magnet Withers	0.19	0.033	3,869		
Old Ocean	0.14	0.029	1,132		
Raccoon Bend	0.19	0.048	2,409		
Sour Lake	0.14	0.016	1,058		25
Spindletop	0.15	0.03	328		
Thompson	0.25	0.029	12,885		25
Webster	0.21	0.046	16,206		
West Columbia	0.21	0.055	1,351		
DISTRICT 4					
Agua Duke-Stratton	<.1	0.015	2,518		
Alazan North	0.04	0.014	3,723		
Borregas	<.1	0.029	4,818		
Government Wells N.	0.22	0.043	511		
Kelsey	0.13	0.008	6,059		25
La Gloria and South	<.1	0.008	936	28	25
Plymouth	0.15	0.049	986		
Seeligson	<.1	0.015	6,424	28	28
Tijerina-Canales-Blucher	<.1	0.010	5,986	28	25
White Point East	0.13	0.02	1,606		
DISTRICT 5					
Mexia	0.20	0.048	109	25	25
Powell	0.31	0.054	109	25	25
Van and Van Shallow	0.8	0.039	12,337		

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.
** All references are to Reference 24 unless otherwise noted.

TABLE 13 (Cont'd.)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References** Sulfur	References** Nitrogen
DISTRICT 6					
East Texas	0.32	0.066	71,139		26
Fairway	0.24	--	14,271		
Hawkins	2.19	0.076	29,054		
Neches	0.13	0.083	3,942		
New Hope	0.46	0.007	292	25	25
Quitman	0.92	0.036	3,103		
Talco	2.98	--	4,380	25	
DISTRICT 7-C					
Big Lake	0.26	0.071	474	25	25
Jameson	<.1	0.034	1,387		
McCamey	2.26	0.139	985		
Pegasus	0.73	0.200	4,052	29	29
DISTRICT 8					
Andector	0.22	0.033	5,694		25
Block 31	0.11	0.032	6,242		
Cowden North	1.89	0.095	9,782		25
Cowden South, Foster, Johnson	1.77	0.127	14,198		
Dollarhide	0.39	0.074	7,592		25
Dora Roberts	<.1	0.023	3,066		
Dune	3.11	0.111	11,425		
Emma and Triple N	<.1	0.025	3,030		
Fuhrman-Mascho	2.06	0.085	1,935		
Fullerton	0.37	0.041	6,607		
Goldsmith	1.12	0.079	20,951		
Headlee and North	<.1	0.083	1,460		
Hendrick	1.73	0.094	766		
Howard Glasscock	1.92	0.096	6,606		
Iatan East	1.47	0.120	3,687		
Jordan	1.48	0.10	3,212		
Kermit	0.94	0.092	2,007		
Keystone	0.57	0.042	8,322		
McElroy	2.37	0.080	9,015		
Means	1.75	0.205	7,921		
Midland Farms	0.13	0.080	6,059		
Penwell	1.75	0.205	2,044		
Sand Hills	2.06	0.085	6,606		
Shafter Lake	0.25	0.041	2,956		
TXL	0.36	0.067	4,854		
Waddell	1.69	0.098	4,453		
Ward South	1.12	0.08	803		
Ward Estes North	1.17	0.107	10,184		
Yates	1.54	0.150	13,359		

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

TABLE 13 (Cont'd.)

State/Region and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	1971 Production (Thousands of Barrels)*	References** Sulfur	References** Nitrogen
DISTRICT 8-A					
Cogdell Area	0.38	0.063	14,235		25
Diamond M	0.20	0.131	7,373		25
Kelly-Snyder	0.29	0.066	52,487		
Levelland	2.12	0.136	9,746		
Prentice	2.64	0.117	5,913		
Robertson	1.37	0.100	2,774		
Russell	0.77	0.078	4,234		
Salt Creek	0.57	0.094	9,271		
Seminole	1.98	0.106	9,125		
Slaughter	2.09	--	35,515		
Spraberry Trend	0.18	0.173	18,688		
Wasson	1.14	0.065	51,210		
DISTRICT 9					
KMA	0.31	0.068	2,920		
Walnut Bend	0.17	0.05	3,942		
DISTRICT 10					
Panhandle	0.55	0.067	14,235		
UTAH					
Greater Aneth	0.20	0.059	7,660		
Greater Redwash	0.11	0.255	5,800		
WYOMING					
Elk Basin (Mont.-Wyo.)	1.78	0.185	14,380		
Garland	2.99	0.290	3,500		
Grass Creek	2.63	0.311	3,760		
Hamilton Dome	3.04	0.343	4,500		
Hilight	--	--	11,300		
Lance Creek	0.10	0.055	325	30	30
Lost Soldier	1.21	0.076	4,820		
Oregon Basin	3.44	0.356	12,260		
Salt Creek	0.23	0.109	11,750		

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* Oil and Gas Journal, January 31, 1972, pp. 95-100.

** All references are to Reference 24 unless otherwise noted.

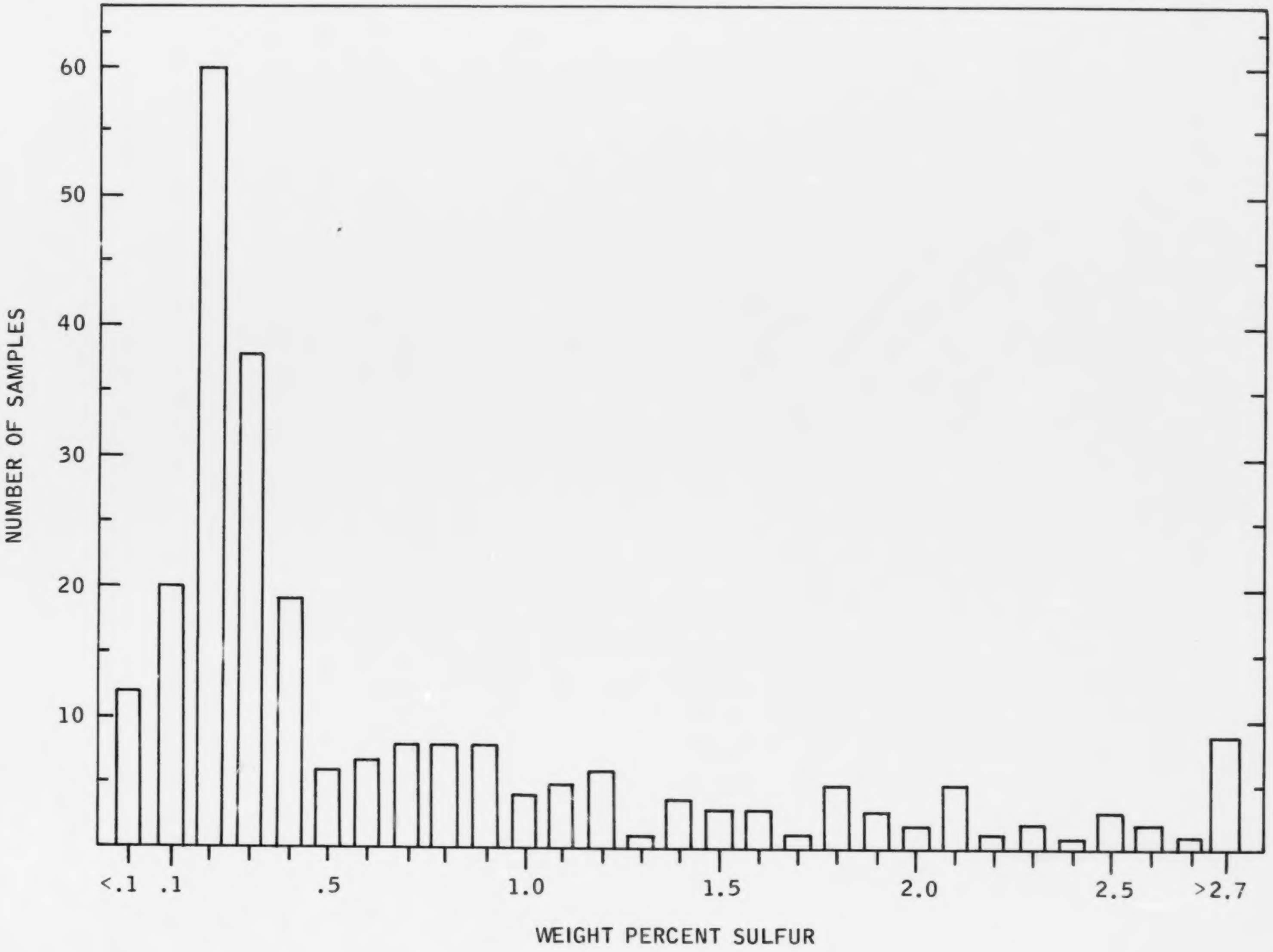
The data presented in Table 13 were evaluated on both a production and a geometric average basis. These evaluations are discussed below by element.

Sulfur - The sulfur data were plotted as a histogram. The resulting frequency distribution is shown as Figure 5. In this figure, each sulfur percentage increment covers a range centering on the value shown. For example, the sulfur value of 0.3 covers a range of 0.25 to 0.3499% sulfur. The sulfur data are log normally distributed about the 0.2% level, although the distribution possesses a long tail. A distribution of this type is the classic one found for the distribution of many trace elements in the earth's crust.

The geometric mean of the sulfur data as calculated from Table 13 was 0.42%. A production average calculated from this same data was 0.77% S, indicating that certain large production fields possessed a greater than average sulfur content. Crudes possessing a sulfur level of <0.1 were treated as if this level were 0.1 for calculation purposes.

The sulfur data ranged from less than 0.1% for a number of fields in southern Texas near the Gulf Coast (Texas Railroad Commission Corpus Christi District 4) to 5.07% and 4.99% for the Cat Canyon West and Santa Maria Valley fields of the coastal area of California.

Figure 5
FREQUENCY DISTRIBUTION OF SULFUR CONTENT
IN CRUDE OILS OF U.S. GIANT OIL FIELDS



__Nitrogen__ - A histogram of the nitrogen data is shown in Figure 6. As with the sulfur graph, each nitrogen percentage increment is centered on the value shown so that the value of 0.25 covers a range of 0.24 to 0.2599% N. Once again the data appear to be log normally distributed with a long tail. The modal value occurs at 0.03% N.

The geometric mean of the nitrogen data of Table 13 was 0.028%. This is in contrast to a production average of 0.159%. As with sulfur content, substantial production from high nitrogen content fields has made the production average greater than the geometric mean.

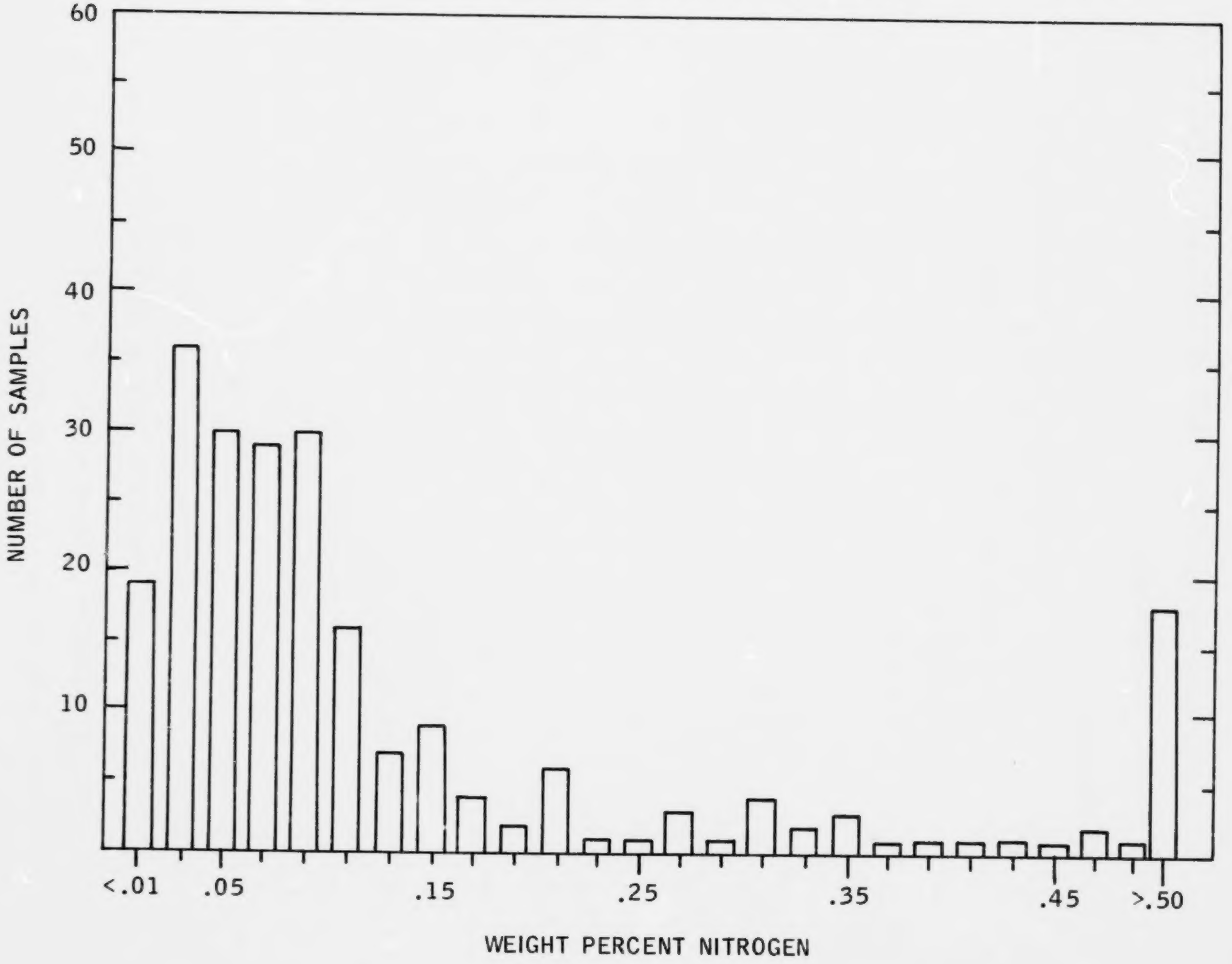
The lowest nitrogen level, 0.002%, was observed for crude from the recently discovered Jay field in Florida. The highest, 0.913%, was found for crude from the San Ardo field in the coastal region of California. It is well known that many California crudes possess very high nitrogen as well as sulfur levels. Consequently, it was not unexpected that all crudes possessing nitrogen levels above 0.5% were from California.

2.2 Other Trace Element Data

With the exception of sulfur and nitrogen, the Bureau of Mines has not performed trace element analysis as part of their routine analyses of crude oils. This factor, coupled with the lack of widespread published data in this area from other sources, means that a large gap exists in reliable information on trace elements. Consequently, no complete trace element distribution is possible even for the giant fields.

Figure 6

FREQUENCY DISTRIBUTION OF NITROGEN CONTENT
IN CRUDE OILS OF U.S. GIANT OIL FIELDS



A number of more or less classical instrumental techniques has been used to obtain much of the trace element data that are available. These techniques include flame photometry, atomic absorption, emission spectroscopy, spectrochemical (colorimetric) analysis and x-ray fluorescence. Although most available trace element data especially on vanadium and nickel have been obtained using these techniques, considerable data are now being accumulated on many elements using activation analysis, a nuclear technique. As some of these data are at variance with those obtained using the more classical methods, activation analysis data are presented in a separate section.

Some trace element data on petroleum were published a number of years ago. It is possible that as a greater understanding of preparative and analytical techniques has developed, the ability to obtain reliable data has increased. It is likely, therefore, that the more recent data are more accurate although this is not necessarily so.

Virtually all of the available trace element data for U.S. oil fields were used to compile Table 14. Included are the state, field, analytical method used if available, year of publication and the source of the data. Data are presented from all fields even those that are not significant producers. Conflicting data are also present for certain fields. Data from numerous published sources were utilized irrespective of analytical method or year of publication. No data were averaged. The search was limited to the following elements: V, Ni, Fe, As, Be, Cd, Hg, Se, Sb, Ba, Cr, Pb, Mn, Mo, Te, Sn. However, for the most part, data were found only for 10 of these elements. Data are presented in the order V, Ni, Fe, Ba. Cr, Mn, Mo, Sn plus the available data for other elements. The authors of reference 31 were contacted to ascertain the analytical technique which they utilized. The data of reference 32 were converted from percent ash to ppm of each trace element on an oil basis. The accuracy suggested by the number of significant figures in reporting the analytical results is that of each author except for the data of reference 32 which, on conversion to ppm, were rounded to be conservatively representative of the analysis technique employed.

TABLE 14

TRACE ELEMENT CONTENT OF U.S. CRUDE OILS

State and Field	Trace Element, ppm									Analytical Method	Year	Ref.
	V	Ni	Fe	Ba	Cr	Mn	Mo	Sn	Hg			
ALABAMA												
Toxey	9	14								Emission spectroscopy	1971	31
Toxey	10	16								Emission spectroscopy	1971	31
ALASKA												
Kuparuk, Prudhoe Bay	32	13								Emission spectroscopy	1971	31
Kuparuk, Prudhoe Bay	28	12								Emission spectroscopy	1971	31
McArthur River, Cook Inlet	nd	nd								Emission spectroscopy	1971	31
Prudhoe Bay	31	11								Emission spectroscopy	1971	31
Put River, Prudhoe Bay	16	6								Emission spectroscopy	1971	31
Redoubt Shoal, Cook Inlet	nd	4								Emission spectroscopy	1971	31
Trading Bay, Cook Inlet	nd	nd								Emission spectroscopy	1971	31
ARKANSAS												
Brister, Columbia	nd	nd								Emission spectroscopy	1971	31
El Dorado, East	12	11								Emission spectroscopy	1971	31
Schuler	15.2	10.3	1.2	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
Smackover	nd	4								Emission spectroscopy	1971	31
Stephens-Smart	18.5	22.7	6.3	<1	<1	<1	nd	<1		Emission spectroscopy	1961	32
Tubal, Union	nd	nd								Emission spectroscopy	1971	31
West Atlanta	<1	<1	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
CALIFORNIA												
Ant Hill	14.3	66.5	28.5	<1	<1	nd	nd	nd		Emission spectroscopy	1961	32
Arwin	9.0	28.0								Emission spectroscopy	1956	33
Bradley Sands	134.5	--								(1)	1958	37
Cat Canyon	128	75								Emission spectroscopy	1971	31
Cat Canyon	209	102								Emission spectroscopy	1971	31
Coalinger	5.1	21.9	5.1	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Coal Oil Canyon	6.0	20.0								Emission spectroscopy	1956	33
Coles Levee	11.0	31.0								Emission spectroscopy	1956	33
Coles Levee	2.2	21.6	2.2	<1	<1	nd	<1	nd		Emission spectroscopy	1961	32
Cuyama	10.0	32.0								Emission spectroscopy	1956	33
Cymric	30.0	43.0								Emission spectroscopy	1956	33
Cymric	0.8	2.3	2.0							Emission spectroscopy	1961	34
Cymric									2.6 2.4 1.9	Emission spectroscopy	1961	34
Cymric	0.6	1.1	2.0							Emission spectroscopy	1961	34
Cymric									21.0 14.0 2.9	Emission spectroscopy	1961	34
Cymric	1.0	2.0	2.0							Emission spectroscopy	1961	34
Edison	6.0	11.0								Emission spectroscopy	1956	33
Elk Hills	8.3	38.5	38.5	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Elwood South	nd	11								Emission spectroscopy	1971	31
Gibson	37	125								X-ray fluorescence	1969	35
Gots Ridge	188	80								Emission spectroscopy	1971	31
Helm	14.0	27.0								Emission spectroscopy	1956	33
Helm	2.5	10.5	2.5	<1	<1	nd	nd	<1		Emission spectroscopy	1961	32
Huntington Beach	29	104								Emission spectroscopy	1971	31
Inglewood	125.7	125.7	125.7	<1	1.3	nd	<1	nd		Emission spectroscopy	1961	32
Kettleman	34.0	35.0	24.0							Colorimetric	1952	36
Kettleman Hills	11.0	24.0								(1)	1958	37
Las Flores	106.5	--								(1)	1958	37
Lompoc	37.6	--								(1)	1958	37
Lompoc	199	90								Emission spectroscopy	1971	31
Lost Hills	39.0	8.0								Emission spectroscopy	1956	33
Midway	82.6	82.6	82.6	1.8	1.8	<1	<1	nd		Emission spectroscopy	1961	32
Nicolai	246.5	--								(1)	1958	37
North Belridge	--	107								X-ray fluorescence (inter. std)	1959	38
North Belridge	--	80								Colorimetric	1959	38
North Belridge	--	83								Emission spectroscopy	1959	38
North Belridge	23	83								X-ray fluoresc. (ext. std.)	1960	39
Orcutt	162.5	--								(1)	1958	37
Oxnard	403.5	--								(1)	1958	37
Purisma	218.5	--								(1)	1958	37
Raisin City	8.0	21.0								Emission spectroscopy	1956	33

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(1) Not specified.

nd Sought but not detected.

TABLE 14 (Cont'd)

State and Field	Trace Element, ppm									Analytical Method	Year	Ref.
	V	Ni	Fe	Ba	Cr	Mn	Mo	Sn	As			
Rio Bravo	--	2.2								X-ray fluorescence (int. std.)	1962	40
Rio Bravo	--	--	2.6							X-ray fluorescence (int. std.)	1960	41
Rio Bravo	--	--	2.5							Emission spectroscopy	1960	41
Russell Ranch	12.0	26.0								Emission spectroscopy	1956	33
San Joaquin	44.8	--								(1)	1958	37
Santa Maria	223	97	17							Colorimetric	1952	36
Santa Maria	202	--								(1)	1958	37
Santa Maria	180	106								Emission spectroscopy	1956	33
Santa Maria	280	130								Emission spectroscopy	1960	39
Santa Maria Valley	207	97								Emission spectroscopy	1971	31
Santa Maria Valley	240	--								X-ray fluorescence (int. std.)	1960	41
Santa Maria Valley	280	--								X-ray fluorescence (int. std.)	1960	41
Santa Maria Valley	174	174	1.7	<1	1.7	<1	4.0	nd		Emission spectroscopy	1961	32
Signal Hill	28	--								(1)	1958	37
Signal Hill	25	57								Emission spectroscopy	1956	33
Tejon Hills	64	44								Emission spectroscopy	1956	33
Ventura	42	51								Emission spectroscopy	1956	33
Ventura	49	33	31							Colorimetric	1952	36
Ventura Avenue	25.2	--								(1)	1958	37
Wheeler Ridge	7	1.9								Emission spectroscopy	1956	33
Wilmington	43	61								Emission spectroscopy	1956	33
Wilmington	41	46	28							Colorimetric	1952	36
Wilmington	53	51								Emission spectroscopy	1971	31
Wilmington	--	53								X-ray fluorescence (int. std.)	1959	38
Wilmington	--	60								X-ray fluorescence (int. std.)	1959	38
Wilmington	46	60								Emission spectroscopy	1960	39
Wilmington	36.0	84	36	3.6	<1	nd	1	nd		Emission spectroscopy	1961	32
COLORADO												
Badger Creek	<1	<1	<1	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Badger Creek	<1	<1	<1	<1	nd	<1	<1	<1		Emission spectroscopy	1961	32
Gramps	<1	<1	<1	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Gramp	<1	<1	<1	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Hiawatha	<1	<1	<1	<1	<1	<1	nd	<1		Emission spectroscopy	1961	32
Moffat Dome	<1	<1	<1	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Rangely	2.7	<1	<1	<1	<1	<1	nd	<1		Emission spectroscopy	1961	32
Rangely	<1	<1	6.6	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Rangely	<1	<1	2.7	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Seep	0.24	4.70								Emission spectroscopy	1956	42
White River Area	<1	<1	96.0	<1	<1	2.2	nd	2.2		Emission spectroscopy	1961	32
FLORIDA												
Jay	nd	1								Emission spectroscopy	1971	31
ILLINOIS												
Loudon	1.22	0.62	0.57							Emission spectroscopy	1952	43
Loudon	0.56	--								(1)	1958	37
KANSAS												
Brewster	2.1	1.3	<1	<1	<1	nd	nd	nd		Emission spectroscopy	1961	32
Brewster	<1	3.9	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
Brock	1	2.4	10.2	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Coffeyville	3.8	1.2	7.2	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Cunningham	44.2	9.9	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
Cunningham	24.0	24.0	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
Iola	15.6	9.0	3.9	2	<1	<1	nd	nd		Emission spectroscopy	1961	32
Iola	4.5	4.5	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
"Kansas-1"	--	>5							< .021	Emission spectroscopy	1966	44
"Kansas-2"	--	>21							< .08	Emission spectroscopy	1966	44
McLouth	<1	6.3	<1	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Otis Albert	21.3	6.0	<1	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Otis Albert	39.0	9.1	9.1	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
Pawnee Rock	12.3	3.4	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32
Rhodes	145	--								X-ray fluorescence (int. std.)	1960	41
Rhodes	165	--								Emission spectroscopy	1960	41
Rhodes	133	--								X-ray fluorescence (int. std.)	1960	39
Rhodes	--	36								X-ray fluorescence (int. std.)	1960	41
Rhodes	--	38								Emission spectroscopy	1960	41
Rhodes	--	32								X-ray fluorescence (int. std.)	1959	38
Solomon	30	7	<1	<1	<1	<1	nd	nd		Emission spectroscopy	1961	32

---

(1) Not specified

nd Sought but not detected

TABLE 14 (Cont'd)

State and Field	Trace Element, ppm V	Ni	Fe	Ba	Cr	Mn	Mo	Sn	As	Analytical Method	Year	Ref.
LOUISIANA												
Bay Marchard	nd	2								Emission spectroscopy	1971	31
Colquitt, Clairborne	nd	nd								Emission spectroscopy	1971	31
Colquitt, Clairborne	nd	nd								Emission spectroscopy	1971	31
Colquitt, Calirborne (Smackover B)	nd	nd								Emission spectroscopy	1971	31
Delta (West) Offshore, Block 117	nd	2								Emission spectroscopy	1971	31
Delta (West) Block 27	nd	2								Emission spectroscopy	1971	31
Delta (West) Block 41	nd	2								Emission spectroscopy	1971	31
Eugene Island, Offshore, Block 276	4	nd								Emission spectroscopy	1971	31
Eugene Island, Offshore, Block 238	nd	nd								Emission spectroscopy	1971	31
Lake Washington	nd	4								Emission spectroscopy	1971	31
Main Pass, Block 6	nd	3								Emission spectroscopy	1971	31
Main Pass, Block 41	nd	1								Emission spectroscopy	1971	31
Olla	<1	5.56	0.07							Emission spectroscopy	1952	43
Ship Shoal, Offshore, Block 176	nd	nd								Emission spectroscopy	1971	31
Ship Shoal, Offshore, Block 176	nd	nd								Emission spectroscopy	1971	31
Ship Shoal, Block 208	nd	2								Emission spectroscopy	1971	31
Shongaloo, N. Red Rock	nd	nd								Emission spectroscopy	1971	31
South Pass, Offshore, Block 62	nd	4								Emission spectroscopy	1971	31
Timbalier, S., Offshore, Block 54	nd	nd								Emission spectroscopy	1971	31
MICHIGAN												
Trent	--	0.23								Emission spectroscopy	1956	42
MISSISSIPPI												
Baxterville, Lamar and Marion	40	15								Emission spectroscopy	1971	31
Heidelberg	15.35	6.02	1.78							Emission spectroscopy	1952	43
Mississippi	--	.7							<.003	Emission spectroscopy	1966	44
Tallhalla Creek, Smith	nd	nd								Emission spectroscopy	1971	31
Tallhalla Creek, Smith	nd	nd								Emission spectroscopy	1971	31
Tallhalla Creek, Smith (Smackover)	nd	nd								Emission spectroscopy	1971	31
Tingley, Yazoo	7	5								Emission spectroscopy	1971	31
MONTANA												
Bell Creek	nd	2								Emission spectroscopy	1971	31
Big Wall	24	13.2		<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Soap Creek	132	13.2		<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
NEW MEXICO												
Rattlesnake	<1	<1	<1	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Rattlesnake	<1	<1	<1	<1	<1	<1	<1	nd		Emission spectroscopy	1961	32
Table Mesa	<1	<1	9.9	<1	<1	<1	<1	<1		Emission spectroscopy	1961	32
OKLAHOMA												
Allurve (Nowata)	<1	<1	1.4	6.0	<1	<1	<1	<1		Emission spectroscopy	1961	32
Allurve (Nowata)	1.1	1.2	51.0	11.9	<1	<1	nd	<1		Emission spectroscopy	1961	32
Allurve (Nowata)	<1	6.0	1.4	6.0	<1	<1	<1	<1		Emission spectroscopy	1961	32
Bethel	--	0.11								Emission spectroscopy	1956	42
Burbank	nd	nd								Emission spectroscopy	1971	31
Cary	0.15	0.65								Emission spectroscopy	1956	42
Chelsea (Nowata)	1.4	1.4	27.0	6.3	<1	<1	nd	nd		Emission Spectroscopy	1961	32
Chelsea (Nowata)	<1	<1	6.0	<1	<1	<1	<1	<1		Emission Spectroscopy	1961	32
Chelsea (Nowata)	<1	<1	<1	3.0	<1	<1	nd	<1		Emission Spectroscopy	1961	32
Cheyarha	0.32	0.70								Emission spectroscopy	1956	42
Cheyarha	0.34	0.95								Emission spectroscopy	1956	42
Cheyarha	0.21	0.36								Emission spectroscopy	1956	42
Cheyarha	0.36	4.10								Emission spectroscopy	1956	42
Cromwell	0.23	0.80								Emission spectroscopy	1956	42
Cromwell	0.11	0.23								Emission spectroscopy	1956	42
Cromwell	0.10	0.23								Emission spectroscopy	1956	42
Cromwell	--	0.27								Emission spectroscopy	1956	42
Cromwell	0.10	0.42								Emission spectroscopy	1956	42
Cromwell	--	0.23								Emission spectroscopy	1956	42
Dill	0.23	2.10								Emission spectroscopy	1956	42
Dover, Southeast	nd	nd								Emission spectroscopy	1971	31
Dustin	--	0.36								Emission spectroscopy	1956	42
E. Lindsay	--	0.10								Emission spectroscopy	1956	42
E. Seminole	0.23	0.46								Emission spectroscopy	1956	42
E. Yeager	--	0.12								Emission spectroscopy	1956	42
Fish	--	0.23								Emission spectroscopy	1956	42
Glen Pool	--	--	5.0							X-ray fluorescence (int. std.)	1960	41

(1) Not specified nd Sought but not detected

TABLE 14 (Cont'd)

State and Field	Trace Element, ppm								Analytical Method	Year	Ref.
	V	Ni	Fe	Ba	Cr	Mn	Mo	Sn			
Grief Creek	0.10	0.42							Emission spectroscopy	1956	42
Hawkins	2.10	8.50							Emission spectroscopy	1956	42
Hawkins	0.72	3.50							Emission spectroscopy	1956	42
Horns Corner	--	0.70							Emission spectroscopy	1956	42
Katie	0.17	0.52							Emission spectroscopy	1956	42
Katie	0.48	1.60							Emission spectroscopy	1956	42
Katie	0.29	1.00							Emission spectroscopy	1956	42
Katie	0.24	1.00							Emission spectroscopy	1956	42
Kendrick	<1	<1	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Konawa	0.10	0.65							Emission spectroscopy	1956	42
Laffoon	44.0	20.2	1.5	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Little River	0.17	1.10							Emission spectroscopy	1956	42
Middle Gilliland	<1	<1	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Naval Reserve	<1	<1	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
New England	<1	<1	<1	nd	<1	<1	nd	nd	Emission spectroscopy	1961	32
N. Dill	0.13	1.45							Emission spectroscopy	1956	42
N. E. Castle Ext.	0.29	1.50							Emission spectroscopy	1956	42
N. E. Elmore	0.15	0.60							Emission spectroscopy	1956	42
N. E. Elmore	0.17	0.70							Emission spectroscopy	1956	42
N. Okemah	0.11	0.70							Emission spectroscopy	1956	42
N. W. Horns Corner	--	0.10							Emission spectroscopy	1956	42
Olympia	0.88	2.40							Emission spectroscopy	1956	42
Osage City	2.9	1.6	6.9	nd	<1	<1	nd	nd	Emission spectroscopy	1961	32
S. W. Maysville	1.36	2.10							Emission spectroscopy	1956	42
S. W. Maysville	0.25	1.10							Emission spectroscopy	1956	42
Tatums	--	57							X-ray fluorescence	1959	38
Tatums	--	56							Emission spectroscopy	1959	38
Tatums	148	71							X-ray fluorescence (ext. std.)	1960	39
Weleetka	--	0.10							Emission spectroscopy	1956	42
W. Holdenville	0.13	0.46							Emission spectroscopy	1956	42
W. Wewoka	0.14	0.42							Emission spectroscopy	1956	42
Wewoka	--	0.15							Emission spectroscopy	1956	42
Wewoka Lake	0.33	0.95							Emission spectroscopy	1956	42
Wewoka Lake	0.15	0.30							Emission spectroscopy	1956	42
Wewoka Lake	0.18	0.27							Emission spectroscopy	1956	42
Wildhorse	2.6	1	<1	nd	nd	<1	nd	nd	Emission spectroscopy	1961	32
Wynona	<1	<1	1.8	<1	<1	<1	nd	<1	Emission spectroscopy	1961	32
Wynona	<1	<1	<1	<1	nd	<1	nd	<1	Emission spectroscopy	1961	32
TEXAS											
Anahuac	0.2	1.1	--						Emission spectroscopy	1958	45
Brantley-Jackson, Hopkins	nd	nd	--						Emission spectroscopy	1971	31
Brantley-Jackson, Smackover	nd	nd	--						Emission spectroscopy	1971	31
Conroe	0.008	<1	0.81						Chemical (V); emission (Ni)	1952	43
East Texas	4	3	--						Emission spectroscopy	1971	31
East Texas	1.2	0.88	0.51						Emission spectroscopy	1952	43
East Texas	1.05	1.69	--						Colorimetric	1952	36
East Texas	1.2	1.7	3.2						Colorimetric	1952	36
Edgewood, Van Zandt	nd	nd	--						Emission spectroscopy	1971	31
Finley	2.6	2	5.7	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Jackson	0.9	1.8	4.4						Colorimetric	1952	36
Lake Trammel, Nolan			--						Emission spectroscopy	1971	31
Mirando	1.4	1.9	7.6						Colorimetric	1952	36
Panhandle, Carson	8	3	--						Emission spectroscopy	1971	31
Panhandle, Hutchinson	6	5	--						Emission spectroscopy	1971	31
Panhandle, West Texas	8.4	--	--						(1)	1952	46
Refugio	0.68	0.70	0.34						Chemical	1952	43
Refugio, Light	0.56	--	--						(1)	1958	37
Salt Flat	8.3	1.43	1.71						Chemical	1952	43
Scurry County	0.8	1.0	3.4						Colorimetric	1952	36
Sweden	0.8	0.6	--						Emission spectroscopy	1958	45
Talco	8.8	2.57	2.06						Chemical	1952	43
Talco	5.16	--	--						(1)	1958	37
Wasson	15	nd	--						Emission spectroscopy	1971	31
West Texas	23	5	--						X-ray fluoresc. spectro. (ext. std.) or emission spectroscopy	1960	39
West Texas	6.7	--	--						(1)	1952	46
West Texas	6.3	--	--						Emission spectroscopy	1956	47
West Texas	11.8,	3.8	--						Emission spectroscopy	1958	45
West Texas	8.5	4.2							Emission spectroscopy	1958	45
West Texas	8.96	--	--						(1)	1958	37
West Texas	7.9	4.8	5.1						Colorimetric	1952	36
West Texas (Imogene)	8.5	1.73	0.88						Chemical	1952	43
Yates-Pecos	7.8	2.6	0.11						Chemical	1952	43

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(1) Not specified

nd Sought but not detected

TABLE 14 (Cont'd)

State and Field	Trace Element, ppm V	Ni	Fe	Ba	Cr	Mn	Mo	Sn	Analytical Method	Year	Ref.
UTAH											
Duchesne	<1	<1	3.9	3.9	<1	<1	<1	<1	Emission spectroscopy	1961	32
Duchesne	<1	<1	1.4	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Duchesne County	<1	12.3	12.3	2.9	<1	<1	nd	nd	Emission spectroscopy	1961	32
Red Wash	nd	nd	--						Emission spectroscopy	1971	31
Red Wash	nd	nd	--						Emission spectroscopy	1971	31
Roosevelt	<1	3.2	<1	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Roosevelt	<1	5.4	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Virgin	14.4	14.4	3.4	<1	<1	<1	nd	<1	Emission spectroscopy	1961	32
Virgin	8.1	8.1	1.9	<1	<1	<1	nd	<1	Emission spectroscopy	1961	32
West Pleasant Valley	11.4	57	1140.0	26.6	1.1	11.4	2.7		Emission spectroscopy	1961	32
Wildcat	0.14	7.5							Emission spectroscopy	1956	43
WYOMING											
Beaver Creek	nd	nd							Emission spectroscopy	1971	31
Big Horn Mix	15.97	3.6	0.8						Emission spectroscopy	1952	43
Bison Basin	1.1	2.7	<1	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Circle Ridge	48	11.2	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Corral Creek	59	11	--						Emission spectroscopy	1971	31
Crooks Gap	2.1	2.2	1.0	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Dallas	66	15.4	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Dallas	66	66	1.5	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Derby	39	39	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Elk Basin	38	9.2	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Elk Basin	8.4	2	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Garland	36	24	3.6	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Grass Creek	106.4	28.9	1.1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Half Moon	98.6	27.8	1.7	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Half Moon	50.6	<1	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Hamilton Dome	106.4	26.6	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Hamilton Dome	55.2	8.6	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Hamilton Dome	106.4	24.3	2.7	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Little Mo	83	16	--						Emission spectroscopy	1971	31
Lost Soldier	<1	<1	<1	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Lost Soldier	<1	<1	<1	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Lost Soldier	<1	<1	<1	<1	<1	<1	<1	<1	Emission spectroscopy	1961	32
Mitchell Creek	72.0	72.0	7.2	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
North Oregon Basin	77.0	22.4	1.0	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
North Oregon Basin	72.0	14.8	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
North Oregon Basin	60.0	11.5	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Oil Mountain	144.0	33.6	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Pilot Butte	45.0	10.5	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Pilot Butte	24.0	5.6	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Pine Ridge	nd	nd	--						Emission spectroscopy	1971	31
Prescott No. 3	21.0	7.1	--						(1)	1959	37
Recluse	nd	nd	--						Emission spectroscopy	1971	31
Roelis	88	15	--						Emission spectroscopy	1971	31
Salt Creek	84.0	8.4	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Salt Creek	1.4	1.4	<1	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Salt Creek	<1	<1	23.4	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Salt Creek	<1	3.9	3.9	<1	<1	<1	nd	nd	Emission spectroscopy	1961	32
Skull Creek	--	0.42							Emission spectroscopy	1956	42
South Casper Creek	12.9	3.0	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
South Fork	21.9	21.9	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
South Spring Creek	102.0	102.0	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
South Spring Creek	117.0	27.3	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Steamboat Butte	29.1	6.79	<1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32
Washakie	74.0	25.0	--						(1)	1934	37
Winkleman Dome	48.0	11.2	1	<1	<1	<1	<1	nd	Emission spectroscopy	1961	32

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(1) Not specified

nd Sought but not detected.

The trace element data presented in Table 14 indicate that, in general, the lowest metal content domestic crudes are from the coastal and offshore fields of Louisiana and Texas. The highest metal content crudes are found in California. This parallels the observations made for sulfur and nitrogen. It is not surprising that the levels of nitrogen, vanadium and nickel should vary together because some nitrogen and some of these (and other) metals are frequently bound into a porphyrin ring(48). This type of chelate coordination complex is known for its high stability. All of the volatile metal compounds present in crude oil are metalloporphyrins. The nature of the nonvolatile metal compounds is not completely understood although they too may be complexes with more than one porphyrin ring or simple porphyrins with sizeable asphaltic side chains.

Data obtained from the Cymric field of California's San Joaquin Valley are worthy of comment. The high mercury levels reported for this field are in no way representative of domestic production in general or of California production in particular. Cymric's high mercury content can be attributed to its location on the southeast prolongation of the main mercury belt east of the San Andreas fault. It is, therefore, not surprising that the mercury ore cinnabar found in this region is saturated with hydrocarbons and that crude oil hydrocarbons appear to be saturated with mercury(49).

3. Imported Crude Oils

As noted previously, approximately 15% of the nation's total crude oil supply in 1971 was obtained from imported sources. This percentage is increasing as U.S. demand grows and domestic production declines. Import data for 1971 are shown in Table 15.

Crude oils are found in a number of locations throughout the world. It is not surprising, therefore, that there is a wide difference in the quality of foreign crude oils. Some possess negligible trace element concentrations while others have trace element levels considerably higher than the bulk of domestic production. However, as noted in Table 15, the crudes imported into the U.S. come from only a few regions thus permitting a generalized breakdown of their pertinent characteristics. This summary is presented in Table 16. The presentation of generalizations does not imply that there are no significant variations among the crude oils of a given region, or even a given nation. As the U.S. data illustrate this is not to be expected. Rather, these generalized characteristics are those possessed by the crudes of the largest fields in a given region. As in the U.S., it is these large fields that dominate production, are representative of the region and are most likely to be imported into the U.S. It is also these fields about which published data are generally more readily available.

TABLE 15

IMPORTS OF CRUDE OIL INTO THE U.S. BY COUNTRY OF ORIGIN IN 1971(23)

Region	Exporting Country	Import Level, Thousands of Barrels/Day	% of Imported Crude
NORTH AMERICA			
	Canada	756	45.42
SOUTH AMERICA			
	Venezuela	323	19.40
	Colombia	6	0.36
	Bolivia	3	0.18
	Chile	1	0.06
	Total South America	333	20.00
MIDDLE EAST			
	Saudi Arabia and Neutral Zone	119	7.15
	Abu Dhabi	83	4.98
	Iran	73	4.38
	Kuwait	29	1.74
	Iraq	6	0.36
	Total Middle East	310	18.61
AFRICA			
	Nigeria	76	4.56
	Libya	49	2.94
	Egypt	22	1.32
	Angola	5	0.30
	Algeria	2	0.12
	Total Africa	154	9.24
ASIA			
	Indonesia	112	6.73
	Total Imported Crude	1,665	100.00

TABLE 16

GENERAL CRUDE OIL CHARACTERISTICS BY REGION

Region	Country	Area	Characteristics
NORTH AMERICA	Canada	Alberta/B.C.	Similar to U.S. Midcontinent.
		Saskatchewan/ Manitoba	Medium to high S and trace elements.
SOUTH AMERICA	Venezuela	Lake Maracaibo	Medium to high S. High vanadium and other trace elements
		Tar Belt	Very high sulfur and trace elements
	Colombia		Low S and trace elements in export crude
AFRICA	Algeria, Libya Nigeria and other West African		Low sulfur and trace elements but medium nitrogen in relation to sulfur.
MIDDLE EAST	Saudi Arabia, Iran etc.		High sulfur and moderate trace elements. Sulfur higher and trace elements lower than Maracaibo crudes.
ASIA	Indonesia		Negligible trace elements

3.1 Sulfur and Nitrogen Data

The sulfur and nitrogen data obtained for oil fields of nations which export crude oil to the U.S. are presented in Table 17. The crude oil characteristics are considered representative of the countries listed in Table 15.

Because data were available for a number of fields with insignificant production, the fields selected to be included in this table were, for the most part, limited to those fields listed under "Worldwide Production" in the Oil and Gas Journal of December 27, 1971. Production statistics for most of the significant oil fields of each oil producing nation are included in this OGJ list. For the purposes of this study, those fields not included are considered to contribute insignificantly to that nation's total production and consequently would not be representative of oil exported to the U.S. Generally, data were available for most of the largest significant fields within a given nation. There were, however, a number of significant fields for which no trace element data could be obtained.

Data were acquired from a wide variety of sources believed to be reliable. When duplicate determinations were available, the data were averaged even if the data were obtained in different laboratories from samples analyzed at different times. Again, published data took precedence over that obtained from other sources.

TABLE 17

SULFUR AND NITROGEN CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

NORTH AMERICA

Province and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References	
				S	N
Canada					
Acheson, Alta.	0.46	--	9,400	50,51	--
Bantry, Alta.	2.41	--	6,900	50	--
Bonnie Glen, Alta.	0.32	--	36,800	50,51	--
Boundary Lake, B.C.	0.72	--	27,700	51	--
Coleville, Sask.	2.62	0.126	4,700	50,51	52
Daly, Manitoba	0.18	--	1,400	50	--
Dollard, Sask.	2.18	--	8,800	50,51	--
Excelsior, Alta.	0.71	0.027	1,600	51,53	52
Fenn - Big Valley, Alta.	1.89	--	19,600	51,53	--
Fosterton-Dollard, Sask.	2.91	0.120	7,600	50,51,53	--
Gilby, Alta.	0.12	--	5,300	51	--
Golden Spike, Alta.	0.37	--	37,400	51,53	--
Harmattan, East, Alta.	0.37	--	6,000	51	--
Harmattan-Eklton, Alta.	0.44	--	4,500	51	--
Innisfail, Alta.	0.58	--	5,500	51	--
Joarcam, Alta.	0.13	--	5,900	51	--
Joffre, Alta.	0.56	--	6,600	51	--
Kaybob, Alta.	0.04	--	10,900	51	--
Leduc, Alta.	0.53	0.016	16,700	50,51,54	52
Lloydminster, Alta.	3.67	--	2,200	50,54	--
Midale, Sask.	2.24	--	11,700	51	--
North Premier, Sask.	2.92	--	6,300	50	--
Pembina, Alta.	0.22	--	140,000	50,51	--
Redwater, Alta.	0.22	0.041	58,000	50	52
Steelman, Sask.	0.73	--	28,200	51	--
Stettler, Alta.	1.59	0.055	3,200	50,51	52
Sturgeon Lake, S., Alta.	0.85	--	11,700	51	--
Swan Hills, Alta.	0.46	0.034	76,900	53	52,53
Taber, East, Alta.	3.08	--	4,500	50	--
Taber, West, Alta.	2.55	--		50	--
Turner Valley, Alta.	0.34	--	2,900	51	--
Virden-Roselea, Man.	1.43	--	3,700	51	--
Virden-North Scallion, Man.	1.47	--	7,500	51	--
Wainwright, Alta.	2.60	--	10,800	55	--
Westerose, Alta.	0.25	--	9,400	51	--
West Drumheller, Alta.	0.51	--	1,900	50,51	--
Weybum, Sask.	1.89	--	33,300	51	--
Wizard Lake, Alta.	0.24	0.023	27,600	51	52

SOUTH AMERICA

Field and State	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Venezuela					
Aguasay, Monagas	0.82	--	14,800	53,54	--
Bachaquero, Zulia	2.65	0.377	738,900	53	53,54
Boca, Anzoategui	0.89	0.178	6,100	54	54
Boscan, Zulia	5.54	0.593	68,400	53	53,57
Cabimas, Zulia	1.71	0.249	82,000	53,54	53,54
Caico Seco, Anzoategui	0.13	--	4,200	54	--
Centro del Lago, Zulia	1.42	--	132,200	54	--
Ceuta, Zulia	1.36	--	63,800	56	--
Chimire, Anzoategui	1.07	0.119	17,100	53	53,54
Dacion, Anzoategui	1.29	0.274	10,900	53	53,54
El Roble, Anzoategui	0.10	0.001	1,000	54	54
Guara, Anzoategui	2.95	0.314	26,900	53	53
Guario, Anzoategui	0.13	0.003	1,100	51	54
Inca, Anzoategui	--	0.223	9,500	--	54
La Ceibita, Anzoategui	0.41	0.055	14,300	53	53
Lago Medio, Zulia	1.16	--	58,100	56	--
Lagunillas, Zulia	2.15	0.319	940,100	51,53	53,54
Lama, Zulia	1.47	0.203	320,000	53	53
La Paz, Zulia	1.29	--	23,500	54	--
Leona, Anzoategui	1.38	--	11,900	56	--
Mapiri, Anzoategui	0.54	0.058	2,800	54	54
Mara, Zulia	1.16	0.116	10,100	53	53,54
Mata, Anzoategui	1.09	0.238	55,800	53	53
Mene Grande, Zulia	2.00	--	12,200	54	--
Mercy, Anzoategui	2.52	0.429	27,500	53	53
Nipa, Anzoategui	0.38	--	29,200	54	--
Oficina, Anzoategui	0.59	0.202	48,100	53	54
Oritupano, Monagas	1.89	--	14,500	54	--
Oscurote, Anzoategui	1.19	--	11,400	54	--
Pilon, Monagas	2.11	0.360	23,900	53	53
Pradera, Anzoategui	0.75	0.033	700	54	54
Quiriquire, Monagas	1.33	0.252	22,000	53	53,54
Ruiz, Guarico	1.05	0.161	600	54	54
San Joaquin, Anzoategui	0.14	0.036	2,300	53	54
Santa Ana, Anzoategui	0.42	--	7,000	54	--
Santa Rosa, Anzoategui	0.09	0.006	34,700	53	53
Sibucara, Zulia	0.82	0.074	2,000	54	54
Silvestre, Barinas	1.17	0.261	12,200	53	53
Sinco, Barinas	1.38	0.284	28,400	53	53
Soto, Anzoategui	0.52	0.159	10,000	54	54
Santa Barbara, Monagas	0.88	0.125	6,100	54	54
Tacat, Monagas	1.55	--	3,500	54	--
Taman, Guarico	0.14	0.025	400	54	54
Temblador, Monagas	0.83	0.338	5,300	54	54
Tia Juana, Zulia	1.70	0.269	373,000	53	53,54
Tucupita, Amacuro	1.05	0.312	3,700	51	54
Yopales, Anzoategui	1.15	0.275	15,700	54	54
Zapatos, Anzoategui	0.48	0.075	19,300	53	53

SOUTH AMERICA (Cont'd) Country and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Colombia					
Casabe	1.07	--	7,500	51	--
Colorado	0.25	--	900	51	--
Galan	1.11	--	1,300	51	--
Infantas	0.88	--	4,500	51	--
La Cira	0.96	--	17,200	51	--
Payoa	0.83	0.147	8,200	53	53
Rio Zulia	0.32	--	23,700	58	--
Tibu	0.71	--	12,900	51	51
Bolivia					
Camiri	0.02	--	2,800	54	--
Chile					
Cerro Manatiales	0.05	--	--	51	--

MIDDLE EAST

Country and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Saudi Arabia and Neutral Zone					
Abqaiq	2.03	0.105	892,500	53	53
Abu Hadriya	1.69	--	103,700	51	--
Abu Sa'Fah	2.61	0.232	82,900	53	53
Berri	2.24	0.206	155,900	53	53
Dammam	1.47	--	21,600	51,54	-
Fadhili	1.25	0.029	47,900	53	53
Ghawar	1.89	0.107	2,057,900	53	53
Khafji	2.99	0.159	--	53	53
Khursaniya	2.53	0.093	74,300	53	53
Khurais	1.73	0.307	22,300	53	53
Manifa	2.75	0.338	5,100	53	53
Qatif	2.55	0.109	95,100	53	53
Safaniya	2.88	0.126	791,400	53	53
Wafra	3.91	0.145	141,000	53,54,56	53,54
Abu Dhabi					
Bu Hasa I	0.74	0.032	--	53	53
Bu Hasa II	0.77	0.031	--	53	53
Habshan	0.71	0.026	--	53	53
Murban-Bab-Bu Hasa	0.62	0.028	564,100	53	53
Iran					
Agha Jari	1.41	0.015	848,000	53	53
Cyrus	3.68	0.300	24,000	53	53
Darius	2.44	0.089	100,000	53	53
Gach Saran	1.57	0.226	882,000	51,53	53
Haft Kel	1.20	--	45,000	59	--
Naft-i-Shah	0.76	--	10,000	54	--
Sassan	2.06	0.082	137,000	53	53
Kuwait					
Burgan	2.58	0.122	2,950,000	53	53
Magwa-Ahmadi	2.21	0.125		53	53
Minagish	2.12	0.103		53	53
Raudhatain	2.13	0.102		53	53
Sabriyah	1.62	0.096		53	53
Iraq					
Bai Hassan	1.36	0.28	57,000	60	60
Kirkuk	1.93	--	1,097,000	51	--
Rumaila	2.1	--	480,000	56	--

AFRICA

Country and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Nigeria					
Afam	0.09	0.027	8,400	61	61
Apara	0.11	0.050	1,000	61	61
Bomu	0.20	0.084	46,000	61	61
Delta	0.18	0.096	69,800	53	53
Ebubu	0.20	0.113	2,600	61	61
Imo River	0.20	0.121	104,100	61	61
Meji	0.15	0.041	19,400	53	53
Meren	0.09	0.048	82,700	53	53
Obagi	0.21	0.060	43,100	53	53
Oloibiri	0.26	0.179	4,200	61	61
Umuechem	0.14	0.076	32,800	61	61
Libya					
Amal	0.14	0.093	162,400	61	61
Beda	0.45	0.203	7,900	61	61
Bel Hedan	0.24	0.120	6,600	61	61
Brega*	0.22	--		56	--
Dahra	0.41	0.106	33,300	53,61	53,61
Defa	0.28	0.140	165,800	61	61
El Dib	1.04	0.127	2,200	53	53
Es Sider*	0.42	0.160		60	60
Farrud	0.39	0.070	4,500	53	53
Gialo	0.56	0.121	359,400	61	61
Hofra	0.32	0.082	5,200	61	61
Kotla	0.84	0.274	11,900	61	61
Nafoora	0.55	0.091	238,800	53	53
Ora	0.23	0.119	11,300	53,61	53,61
Rakb	0.23	0.118	11,500	61	61
Samah	0.25	0.127	57,000	61	61
Sarir	0.16	0.079	440,000	53	53
Umm Farud	0.13	0.033	4,200	53	53
Waha	0.24	0.134	129,300	61	61
Zaggut	0.30	0.188	2,700	61	61
Zelten	0.23	0.090	357,900	61	61

* Export crude mixture delivered to pipeline terminals.

AFRICA (Cont'd)

Country and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Egypt					
Asl	2.05	--	*	53	--
El Alamein	0.84	0.075	24,600	53	53
El Morgan	1.67	0.183	260,900	53	53
Sudr	2.06	--	*	53	--
Angola (Cabinda)					
Tobias	1.51	--	--	58	--
Algeria					
Edjeleh	0.095	0.058	18,900	53	53
Gassi Touil	0.020	0.008	59,000	61	61
Hassi Messaoud	0.15	0.018	387,200	53	53
Ohanet	0.06	--	8,600	58	--
Rhourde el Baguel	0.31	0.087	65,900	61	61
Tin Fouye	0.13	0.061	46,200	53	53
Zarzaitine	0.06	0.018	44,200	53	53

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* These fields on the Sinai Peninsula are being produced by Israel. Data are not available.

ASIA

Country and Field	Sulfur, Weight Percent	Nitrogen, Weight Percent	Production, bbl/day	References S	References N
Indonesia					
Bekasap	0.17	0.124	111,100	53	53
Duri	0.18	0.337	37,900	53	53
Kalimantan	0.07	--	--	54	--
Lirik	0.08	--	4,500	58	--
Minas	0.115	0.132	408,700	53	53
Pematang	0.10	0.159	67,300	53	53
Seria	<.10	--	--	53	--
Tarakan	0.13	--	1,600*	54	--

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* Production data from Reference 58.

3.2 Other Trace Element Data

The trace element data available for worldwide oil fields are limited largely to the elements vanadium and nickel. Data for certain other elements exist on a nation by nation basis. For example, extensive data are available for the iron content of Canadian crude oils. Some additional data are available for the iron and chromium content of the crudes of other nations. The trace element data for crude oils from nations which export to the U.S. are presented in Table 18. All data obtained have been included irrespective of field size. Table 18 lists world region, nation, element content, analytical method used when available, year of publication and source of the data.

TABLE 18

TRACE ELEMENT CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

NORTH AMERICA

Country and Field	Trace Elements, ppm				Analytical Method	Year	Ref.
	V	Ni	Fe	Cr			
Canada							
Acheson	0.53	1.30	0.7		Colorimetric	1954	62
Acheson	3.5	1.88	2.0		Colorimetric	1954	62
Acheson	0.81	4.50	0.7		Colorimetric	1954	62
Armena-Camrose	0.59	0.74	0.8		Colorimetric	1954	62
Bantry	56.9	19.1	1.0		Colorimetric	1954	62
Bawlf	1.94	4.75	4.9		Colorimetric	1954	62
Big Valley	6.83	12.3	1.1		Colorimetric	1954	62
Big Valley	6.14	11.08	0.7		Colorimetric	1954	62
Bonnie Glen	0.04	0.09	0.2		Colorimetric	1954	62
Bonnyville	135	57.0	9.0		Colorimetric	1954	62
Campbell	11.2	4.91	0.7		Colorimetric	1954	62
Cantaur	86.8	33.5	1.3		Colorimetric	1954	62
Cantaur	135.5	52.3	8.4		Colorimetric	1954	62
Chamberlain	17.9	8.64	0.8		Colorimetric	1954	62
Coleville	111	33	--		Emission spectroscopy	1971	31
Coleville	13.3	5.03	4.1		Colorimetric	1954	62
Coleville	105	36	0.9		X-ray fluorescence (int. std)	1962	40
Coleville	95	32	--		X-ray fluorescence (ext. std)	1962	40
Conrad	73.3	25.4	0.7		Colorimetric	1954	62
Daly	7.04	5.26	0.8		Colorimetric	1954	62
Dollard	99.7	48.5	1.7		Colorimetric	1954	62
Drumheller	19.4	9.59	2.0		Colorimetric	1954	62
Drumheller	4.32	13.4	0.3		Colorimetric	1954	62
W. Drumheller	0.55	1.26	1.0		Colorimetric	1954	62
Duhamel	0.67	7.46	0.5		Colorimetric	1954	62
Duhamel	2.85	3.91	0.4		Colorimetric	1954	62
Eastend	83.5	33.0	0.8		Colorimetric	1954	62
Elk Island	0.7	1.66	--		Colorimetric	1954	62
Excelsior	2.82	5.30	0.3		Colorimetric	1954	62
Flat Lake	145	60.2	629		Colorimetric	1954	62
Forget	20.8	12.74	0.3		Colorimetric	1954	62
Fosterton	76.5	30.8	4.6		Colorimetric	1954	62
Glen Park	0.16	1.38	0.6		Colorimetric	1954	62
Golden Spike	0.37	3.63	0.7		Colorimetric	1954	62
Grassy Lake	17.9	5.9	0.2		Colorimetric	1954	62
Gull Lake	97.5	34.2	0.9		Colorimetric	1954	62
Hamilton Lake	1.01	1.98	0.9		Colorimetric	1954	62
Joffre	0.15	0.29	0.9		Colorimetric	1954	62
Joseph Lake	0.48	0.55	0.3		Colorimetric	1954	62
Kathyrn	4.0	2.43	16.5		Colorimetric	1954	62
Lac. Ste. Anne	83.7	26.6	2.4		Colorimetric	1954	62
Leduc	0.56	1.27	0.7		Colorimetric	1954	62
Leduc	0.50	1.23	0.6		Colorimetric	1954	62
Leduc	<0.56	--	--		(1)	1958	37
Lloydminster	105	51.5	3.3		Colorimetric	1954	62
Malmo	0.9	1.19	0.5		Colorimetric	1954	62
Malmo	0.58	0.72	0.2		Colorimetric	1954	62
Malmo	0.83	4.41	0.3		Colorimetric	1954	62
Midway	90.8	40.1	1.8		Colorimetric	1954	62
Morinville	105	31.1	4.2		Colorimetric	1954	62
Morinville	2.21	2.75	0.8		Colorimetric	1954	62
McMurray	220	75.7	75.5		Colorimetric	1954	62
Pembina	0.58	1.24	0.5		Colorimetric	1954	62
N. Premier	77.3	30.5	1.1		Colorimetric	1954	62
Rapdan	103.1	47.5	2.1		Colorimetric	1954	62
Ratcliffe	5.60	7.61	1.0		Colorimetric	1954	62
Redwater	4.03	9.43	0.5		Colorimetric	1954	62
Redwater	4.5	10.6	3.4		(1)	1958	37
Redwater	<0.56	--	--		(1)	1958	37
Roselea	4.26	2.90	0.4		Colorimetric	1954	62
Skaro	0.89	2.51	--		Colorimetric	1954	62
Springburn	1.24	6.24	--		Colorimetric	1954	62
Smiley	1.14	2.84	1.7		Colorimetric	1954	62
Stettler	11.4	15.2	0.7		Colorimetric	1954	62
Stettler	16.2	13.8	0.5		Colorimetric	1954	62
Success	88.0	31.6	4.1		Colorimetric	1954	62
E. Taber	103	38.3	3.5		Colorimetric	1954	62
W. Taber	88.8	36.3	1.0		Colorimetric	1954	62
Wabiskaw	208	76.6	58.7		Colorimetric	1954	62
Wagner	19.4	9.59	2.0		Colorimetric	1954	62
Wapella	29.8	17.0	0.7		Colorimetric	1954	62
Wapella	23.1	13.46	1.5		Colorimetric	1954	62

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(1) Not specified

TABLE 18 (Cont)

TRACE ELEMENT CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

SOUTH AMERICA

Country and Field ( ) *	Trace Elements, ppm V	Ni	Fe	Cr	Analytical Method	Year	Ref.
Venezuela							
Amana (1952 Blend)	29	8			Emission spectroscopy	1971	31
Bachaquero	370	46			Colorimetric	1964	63
Bachaquero	430	--	5.4		X-ray fluorescence	1960	41
Bachaquero	430	52,38, 53			X-ray fluorescence	1962	40
Bachaquero	413	49			Emission spectroscopy	1971	31
Bachaquero	348	45			Emission spectroscopy	1958	45
Bachaquero	320	42	3.9	0.08	(1)	1959	37
Bachaquero	390	45			(1)	1972	32
Bachaquero	370	46			(1)	1972	32
Bachaquero	49	5.5			(1)	1972	32
Bachaquero (2)	413	39			(1)	1972	64
Bachaquero Light	49	5.5			Colorimetric	1964	63
Bachaquero Heavy	390	45			Colorimetric	1964	63
Barinas (3)	117-165	43-57			(1)	1972	32
Boca	48.5	--			(1)	1959	37
Boscan	1400	100			Colorimetric	1964	63
Boscan	1580	123			X-ray fluorescence	1969	35
Boscan	937	119			Emission spectroscopy	1971	31
Boscan	819	112			Emission spectroscopy	1971	31
Boscan	1200	160	60.0	1.0	(1)	1959	37
Boscan	1100	105	6.2		(1)	1959	37
Boscan	1150	--			(1)	1959	37
Cachipo	14	3.3			(1)	1972	32
Cantaura	0.6	--			(1)	1959	37
Centro del Lago	179	30	32.0		(1)	1959	37
Chimire	56	13			Emission spectroscopy	1971	31
Cumarebo	0.7	0.8			Colorimetric	1964	63
Dacion	133	29			Emission spectroscopy	1971	31
Esquina	2.5	--			(1)	1959	37
Esquina	1.3	--			(1)	1959	37
Guanipa	110	27			Colorimetric	1964	63
Guario	1.9	--			(1)	1959	37
Guico (3)	17-63	--			(1)	1959	37
Jusepin	26	5.5			Colorimetric	1964	63
Jusepin	16.8	--			(1)	1959	37
Jusepin	14.8	2.0	4.7		Emission spectroscopy	1952	43
La Ceibita	0.66	--			(1)	1959	37
Lagomar	179	22.0	8.4		(1)	1959	37
Lagotreco	163	15			Emission spectroscopy	1971	31
Lagotreco/Lagocinco	101	--			(1)	1972	32
Lagunillas	290,315	--	7.9		X-ray fluorescence	1960	41
Lagunillas	303	34,29 41			X-ray fluorescence	1962	40
Lagunillas	303	39			X-ray fluorescence	1969	35
Lagunillas	265	35.0			Emission spectroscopy	1958	45
Lagunillas	236	--			(1)	1959	37
Lagunillas	116	8.2	0.97		Emission spectroscopy	1952	43
Lagunillas	151	--			(1)	1959	37
Lagunillas	229	30			Emission spectroscopy	1971	31
Lagunillas Heavy	300	38			Colorimetric	1964	63
Lama	55	12			Emission spectroscopy	1971	31
Lama (7)	8-26	--			(1)	1959	37
Lama	104	--			(1)	1972	32
Lama/Lamar	240-300	22-28			(1)	1972	32
Lamar (2)	4-55	--			(1)	1972	32
La Rosa	185	--			(1)	1959	37
La Rosa	156	10.0	0.83		Emission spectroscopy	1952	43
La Rosa Medium	230	24			Colorimetric	1964	63
Leona (3)	86-140	24-36			(1)	1972	32
Mapiri (3)	11-14	--			(1)	1959	37
Mara	220	18			Colorimetric	1964	63
Mara	206	15			Emission spectroscopy	1971	31
Mara	173	16.3			(1)	1959	37

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* Number in parenthesis indicates number of samples involved.

(1) Not specified

TABLE 18 (Cont)

TRACE ELEMENT CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

SOUTH AMERICA (CONT'D) Country and Field ( )*	Trace Elements, ppm V	 Ni	 Fe	 Cr	Analytical Method	Year	Ref.
Mata, Anzoatequi	130	25			Emission spectroscopy	1971	31
Mata, Anzoatequi	21	5			Emission spectroscopy	1971	31
Merey	290	64			Emission spectroscopy	1971	31
Mercy (2)	242-247	31-59			(1)	1972	32
Mesa (2)	45-56	12.7-15			(1)	1972	32
Monagas	212	--			(1)	1972	32
Motatan #7	390	43			Colorimetric	1964	63
Oficina	129	--			(1)	1959	37
Oficina	54	8			Emission spectroscopy	1971	31
Oficina	37	6			(1)	1972	32
Oficina Light	57	6			Colorimetric	1964	63
Oficina Heavy	62	14			Colorimetric	1964	63
Oscurote (2)	20-68	--			(1)	1959	37
Oscurote, Norte	187	--			(1)	1959	37
Paconsib	164	--			(1)	1972	32
Pedernales	230	87			Colorimetric	1964	63
Pilon	510	98			Colorimetric	1964	63
Pilon	181	72			Emission spectroscopy	1971	31
Quiriquire	95	16			Colorimetric	1964	63
Quiriquire	102	18			Emission spectroscopy	1971	31
Quiriquire	39	--			(1)	1959	37
Quiriquire	31.3	5.9	2.0		Chemical	1952	43
Ruiz (East)	111				(1)	1959	37
San Joaquin	0.6	0.2			Colorimetric	1964	63
San Joaquin	2.3	0.9			Emission spectroscopy	1958	45
San Joaquin	2.4	32.0	13.1	0.024	(1)	1959	37
San Joaquin	11.2	2.0			(1)	1959	37
San Joaquin	0.33	0.14	0.45		Chemical	1952	43
San Roque	<4.5	--			(1)	1972	32
Silvestre	205	63			Emission spectroscopy	1971	31
Tapasito	450	40			Colorimetric	1964	63
Tarra	42.0	6.6	0.49	0.009	(1)	1959	37
Temblador	56	35			Colorimetric	1964	63
Tia Juana	180,185	--			X-ray fluorescence	1960	41
Tia Juana	182	16,20 24			X-ray fluorescence	1962	40
Tia Juana	170	16			X-ray fluorescence	1968	65
Tia Juana	216	24			Emission spectroscopy	1971	31
Tia Juana, Light	100	11			Colorimetric	1964	63
Tia Juana, Medium	200	22			Colorimetric	1964	63
Tia Juana, Medium	185	--			(1)	1959	37
Tia Juana, Medium	134	7.6	2.44		Chemical	1952	43
Tia Juana, Heavy	300	25			Colorimetric	1964	63
Tia Juana, Heavy	303	27			Emission spectroscopy	1971	31
Tia Juana, Heavy	269	--			(1)	1959	37
Tigre	160	28			Colorimetric	1964	63
Tigre	153	31			Emission spectroscopy	1971	31
Tucupita	84	45			Colorimetric	1964	63
Urdaneta	430	--			Colorimetric	1964	63
Zapatos	4	<1			Emission spectroscopy	1971	31
Colombia							
Colombian	101	--			(1)	1959	37
Casabe	135	14.4	18		(1)	1972	32
Payoa	59	13			Emission spectroscopy	1971	31
Tibu-Petrolea	60	9	1.6		(1)	1972	32

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* Number in parenthesis indicates number of samples involved.
(1) Not specified

TABLE 18 (Cont)

TRACE ELEMENT CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

MIDDLE EAST

Country and Field ( )*	Trace Elements, ppm V	Ni	Fe	Cr	Analytical Method	Year	Ref.
Saudi Arabia							
Abqaiq, Arab C	49	7			Emission spectroscopy	1971	31
Abqaiq, Arab C	6	<1			Emission spectroscopy	1971	31
Abqaiq, Arab C	<0.56	--			(1)	1972	32
Abu Sa'Fah	32	12			Emission spectroscopy	1971	31
Abu Sa'Fah	27	10			Emission spectroscopy	1971	31
Ain Dar	51	10			Colorimetric	1964	63
Ain Dar, Zone Arab D	16	3			Emission spectroscopy	1971	31
Arabian Lt. (2)	11-12.4	3-3.7			(1)	1972	32
Berri	24	3			Emission spectroscopy	1971	31
Ghawar	17	2			Emission spectroscopy	1971	31
Haradh, Zone Arab D	24	7			Emission spectroscopy	1971	31
Khurais	8	5			Emission spectroscopy	1971	31
Khursaniyah	18	3			Emission spectroscopy	1971	31
Khursaniyah	18	<1			Emission spectroscopy	1971	31
Manifa	12	1			Emission spectroscopy	1971	31
Safania (3)	48-80	14			(1)	1972	32
Safania, Bahrain	57	20			Emission spectroscopy	1971	31
Shedgum	18	4			Emission spectroscopy	1971	31
Southern Fields	16	4			Emission spectroscopy	1971	31
Southern Arabian Fields	21	4			Emission spectroscopy	1971	31
Uthmaniyah	51	9			(1)	1972	32
Neutral Zone							
Khafji	63	12			(1)	1972	64
Khafji	4	--			(1)	1972	32
Wafra (2)	46-52	7			(1)	1972	32
Wafra	56	--			(1)	1972	32
Abu Dhabi							
Abu Dhabi (2)	nil- 1.5	0.43			(1)	1972	32
Abu Dhabi (Land)	1.3	--			(1)	1972	32
Iran							
Agha Jari	36	--			Colorimetric	1964	63
Ahwaz	23	8			(1)	1972	32
Cyrus	151	39			Emission spectroscopy	1971	31
Cyrus	118	--			(1)	1972	32
Gach Saran	123	33			Emission spectroscopy	1971	31
Gach Saran	145	31			Emission spectroscopy	1971	31
Haft Kel	25	--			(1)	1972	32
Iranian Heavy	107	37			X-ray fluorescence	1968	65
Sassan	16	3			Emission spectroscopy	1971	31
S[illegible]an	10.8	--			(1)	1972	32
Ku[illegible]							
Kuwait	29	8			X-ray fluorescence	1969	35
Kuwait	27	9			X-ray fluorescence	1968	65
Kuwait	22.5	6.6	0.33		(1)	1959	37
Kuwait	22.5	6.0	0.7		(1)	1959	37
Magwa-Ahmadi	43	7			Emission spectroscopy	1971	31
Iraq							
Ain Zalah	95	15			Colorimetric	1964	63
Bai Hassan	19	--			Colorimetric	1964	63
Bai Hassan	10	--			(1)	1971	32
Jambur	6	--			Colorimetric	1964	63
Jambur Bai Hassam	22	--			(1)	1971	32
Kirkuk	30	11			Colorimetric	1964	63
Kirkuk (3)	25-30	10-11			(1)	1971	32
Zubair	20	4			Colorimetric	1964	63
Zubair	13	--			(1)	1971	32

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* Number in parenthesis indicates number of samples involved.
(1) Not specified

TABLE 18 (Cont)

TRACE ELEMENT CONTENT OF CRUDE OILS FROM NATIONS WHICH EXPORT TO THE U.S.

AFRICA

Country and Field ( )*	Trace Elements, ppm V	Ni	Fe	Cr	Analytical Method	Year	Ref.
Nigeria							
Afam, E. Region	<1	<1			Emission spectroscopy	1971	31
Apara, E. Region	<1	1			Emission spectroscopy	1971	31
Bomu, E. Region	<1	2			Emission spectroscopy	1971	31
Delta, Offshore	<1	4			Emission spectroscopy	1971	31
Ebuba, E. Region	<1	5			Emission spectroscopy	1971	31
Imo River, E. Region	4	9			Emission spectroscopy	1971	31
Imo River, E. Region	2	3			Emission spectroscopy	1971	31
Kanuskiri, E. Region	<1	5			Emission spectroscopy	1971	31
Kanuskiri, E. Region	<1	6			Emission spectroscopy	1971	31
Ke, E. Region	<1	<1			Emission spectroscopy	1971	31
Meren, Offshore	<1	<1			Emission spectroscopy	1971	31
"Nigerian Medium"	7	<0.8			X-ray fluorescence	1968	65
Olibiri, E. Region	2	13			Emission spectroscopy	1971	31
Robert Kiri, E. Region	1	2			Emission spectroscopy	1971	31
Tubu, Offshore	<1	<1			Emission spectroscopy	1971	31
Umuechem, E. Region	<1	3			Emission spectroscopy	1971	31
Libya							
Amal, Cyrenaica	<1	<1			Emission spectroscopy	1971	31
Dalira, Concession 32	<1	3			Emission spectroscopy	1971	31
Dalira, Tripolitania	<1	2			Emission spectroscopy	1971	31
Dahra	0.6	--			(1)	1972	32
Defa, Cyrenaica	<1	6			Emission spectroscopy	1971	31
Ed Dib, Tripolitania	7	11			Emission spectroscopy	1971	31
Ed Dib, Tripolitania	7	15			Emission spectroscopy	1971	31
El Sider (2)	0.92-1.8	5-5.6			(1)	1972	32
F-90, Concession 90	<1	<1			Emission spectroscopy	1971	31
Facha, Tripolitania	4	7			Emission spectroscopy	1971	31
Farud, Tripolitania	<1	4			Emission spectroscopy	1971	31
Khuff, Cyrenaica	6	12			Emission spectroscopy	1971	31
Kotla, Concession 47	28	35			Emission spectroscopy	1971	31
Ora, Cyrenaica	<1	<1			Emission spectroscopy	1971	31
Ora, Cyrenaica	<1	6			Emission spectroscopy	1971	31
Rakb, Cyrenaica	<1	6			Emission spectroscopy	1971	31
Sarir, Concession 65	<1	5			Emission spectroscopy	1971	31
Sarir, Concession 65	<1	2			Emission spectroscopy	1971	31
Sarir	<.5	5			X-ray fluorescence	1968	65
Umm Farud, Conces. 92	<1	<1			Emission spectroscopy	1971	31
Zelten	1.1	--			(1)	1972	32
Zueitina	0.7	--			(1)	1972	32
Egypt							
Belayim	23	--			(1)	1972	32
Belayim	120	71.9	58		(1)	1972	32
El Alamein	15	7			Emission spectroscopy	1971	31
El Morgan	52	18			Emission spectroscopy	1971	31
El Morgan	37	24			(1)	1971	66
Algeria							
Gassi Touil	<1	<1			Emission spectroscopy	1971	31
Rourde el Baquel	<1	<1			Emission spectroscopy	1971	31
Zarzaitine	<1	<1			X-ray fluorescence	1968	65
Zarazaitine (2)	0.2-1.5	--			(1)	1972	32
ASIA							
Indonesia							
Bekasap	--	8			Emission spectroscopy	1971	31
Duri	--	33			Emission spectroscopy	1971	31
Minas	--	7			Emission spectroscopy	1971	31
Pematamg	--	11			Emission spectroscopy	1971	31

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* Number in parenthesis indicates number of samples involved.

(1) Not specified

3.3 Interpretation of Imported Crude Data

It is important to consider the data contained in Tables 17 and 18 in light of geographical factors as well as import levels, both present and projected. Canada and to a lesser extent Venezuela have a unique logistical position in relation to the U.S. Because of the tremendous U.S. demand and their relative geographical positions, Canada and Venezuela supply approximately 65% of all crude oil imported into the U.S. Virtually all Canadian exports are to the U.S. and most Venezuelan oil exports ultimately are brought into the U.S. as either crude or petroleum products. It can be anticipated that Canada and Venezuela will continue to be major exporters of crude into the U.S. However, as U.S. crude oil needs increase further, and U.S. domestic production declines, greater quantities of crude will have to be imported. Much of this developing gap in imports will probably come from the Middle East. Thus, in effect, relatively high quality domestic crude will be replaced by the lower quality crudes of the Middle East. This means that a significant increase in overall refining complexity is mandated if this new crude is to be processed into clean fuels. This development has significant implications for Phase III of this program.

The paragraphs that follow discuss in general terms factors relevant to imports on a regional or national basis.

Canada - Approximately two-thirds of Canada's crude oil production comes from the province of Alberta. These crudes are generally of moderately high quality. Most significant Alberta crudes are relatively low in sulfur, nitrogen and the trace elements. Much Alberta crude destined for the U.S. is moved by the Interprovincial pipe line into the U.S. midwest. This pipeline passes southeast from Alberta past the oil fields of Saskatchewan and Manitoba. Crudes from these areas which are also fed into this pipeline are of significantly lower quality. Consequently, the overall composition of the crude oil imported from Canada into the U.S. Midwest can be considered on average to be a mixture of the high quality crude from Alberta with that of lower quality from the central prairie provinces.

Venezuela - Venezuelan crude oils are produced in substantial quantities from two general locations, the Lake Maracaibo region in the Venezuelan state of Zulia and the eastern fields in the states of Anzoategui, Monagas and Guarico. The fields of the Maracaibo Basin (also known as the Bolivar Coastal fields) are by far the largest, with this region being responsible for over 80% of Venezuela's crude oil production. The crudes from Venezuela can vary widely in characteristics irrespective of location. However, Venezuelan crudes generally are known for being high in sulfur and nitrogen and notoriously high in metals content.

Crude oil is exported from both general locations to the U.S. Most crude from the Maracaibo region, however, is shipped to Caribbean refineries for processing before it is imported into the U.S. as fuel oil and other petroleum products. Much imported Venezuelan crude oil is processed for asphalt in the U.S. The asphalt fraction contains most of the metals, sulfur and nitrogen thus freeing the lighter, purer fractions for more valuable use as fuels. Consequently, asphalt manufacture can be regarded as a means of removing contaminants from crude oils.

Middle East - The Middle East is not only the world's largest oil producing region, it possesses the world's greatest petroleum reserves as well. The crudes from the Middle Eastern nations surrounding the Persian Gulf are known for their high sulfur and nitrogen levels and for their moderate trace element content. In the Middle East as is the case elsewhere in the world, the better quality crudes are produced in preference to those of lower quality. The lower quality crude reserves are therefore largely untapped. This means that as the Persian Gulf region is called upon to supply a greater quantity of the world's petroleum needs, the poorer quality fields will become major producers and consequently the overall quality of the crude supplied by this region can be expected to decline.

It should be noted that much Middle Eastern crude oil production is currently transported to Europe and Japan. Only minor amounts are presently shipped to the U.S. As U.S. crude production fails to satisfy the nation's crude oil needs, it can be expected that more oil will be supplied by the Middle East and that the quality of this oil will be somewhat poorer than that indicated by the trace element levels of the largest production fields in Tables 17 and 18.

Africa - Crude oils from most of the African continent are generally of high quality. The primary exception to this generalization is the crude production from Egypt's Suez fields. However, recent discoveries in Egypt's western desert are similar in quality to Libyan crudes and, hence, may become a valuable new source of low sulfur export crude.

4. Activation Analysis

The nuclear technique, activation analysis, has been applied with increasing frequency to the analysis of the trace elements present in crude oils. In this technique a sample is irradiated and the resulting radioactive isotope is analyzed using sophisticated counting apparatus. Since activation is frequently accomplished using neutrons, the term neutron activation analysis, NAA, appears frequently in the literature. Activation analysis possesses several distinct advantages over most analytical techniques used for the elemental analysis of crude oils. These advantages include:

- High sensitivity
- No required sample pretreatment
- Simultaneous determination of a number of elements
- Non destructive to sample
- Measurement unaffected by petroleum matrix

Activation analysis possesses very high sensitivity to a large number of the trace elements contained in crude oils. For example, given a flux of 10^{13} neutrons/second/cm^2, the absolute sensitivity of NAA for 65 to 70 elements under ideal conditions is in the 1 nanogram range when irradiation and counting times approximate one hour each(67). For a one gram sample, this translates to a sensitivity of one part per billion, ppb. Typically, sensitivity approximates 2 ppb for vanadium and 0.1 ppb for manganese when a one gram sample is analyzed. The sensitivity of NAA for S, Pb and Sn is limited, however. Sensitivity to nickel is somewhat limited as well. Limited sensitivity for S makes little difference however since this element usually occurs in appreciable quantities in most crude oils thereby permitting a reliable sulfur measurement. Generally, sensitivity can be increased through the use of longer irradiation periods and by the use of higher fluxes.

Limited sensitivity and additional factors present with other trace element analysis techniques mandate pretreatment of crude oil samples before these techniques can be used. This pretreatment is usually either sample concentration or chemical separation. Most ashing procedures generally used for concentration purposes can cause the loss of the more volatile trace elements such as S, Se, Te, As and Hg. Additionally, the reagents used in the ashing process as well as in separation procedures can add trace quantities of elements through reagent contamination. These substantial sources of error are eliminated when activation analysis is used. Further, the analysis is nondestructive.

Activation analysis is insensitive to crude oil physical properties such as density and viscosity. Additionally the use of NAA for trace elements in petroleum is facilitated by the low neutron-capture cross section of the carbon and hydrogen matrix of the crude oil. However, for this same reason NAA is not an effective tool for the analysis of low levels of nitrogen in crude oils.

Because of the intrinsic capability of activation analysis for analyzing a number of elements it can provide a simultaneous determination of many of the trace elements contained in crude oil. This advantage (also possible with emission spectroscopy) can result in more widespread dissemination of much needed trace metal data.

Table 19 presents trace element data obtained using activation analysis for oil fields and blends of oils from throughout the world. The data are presented according to author. Analyses for only those elements of interest to this program are included.

In general the data presented in Table 7 are not in serious disagreement with trace element content determined using other methods. The origin of the samples used in references 70 and 71 is not clear and may explain why some of these analyses differ from the generally accepted values. For example, the vanadium and nickel values reported for Louisiana crude are unusually high relative to the results reported elsewhere (see Table 14). Additionally, one unusually high mercury value was obtained for a California crude. This value might be for the Cymric or another field which would not be representative of California crude oil production. Further, atypically high sulfur, vanadium and nickel levels are reported for certain Libyan crude samples.

TABLE 19

TRACE ELEMENT CONTENT OF CRUDE OILS AS DETERMINED BY ACTIVATION ANALYSIS

Region	State/Country and Field	Sulfur, Weight Percent	ppm								Reference
			V	Ni	As	Sb	Ba	Mn	Mo	Sn	
NORTH AMERICA	California, Wilmington	1.10	48.0	77.0	<.007	<.01	<.06	0.018	<.15	<.6	68
	Louisiana, Timbalier	0.36	1.0	<4.4	0.05	<.009	0.09	0.027	<.16	0.5	68
	Texas, East Texas	0.29	0.79	<3.7	<.007	<.01	<.06	0.15	<.16	<.4	68
	Texas, Goldsmith	1.60	5.0	<4.1	<.01	<.01	<.06	0.033	<.19	<.6	68
	Texas, Headlee	0.07	<.02	<2.8	<.004	0.017	<.06	<.001	<.1	<1.0	68
	Texas, Kelly-Snyder	0.28	0.6	<2.4	<.006	<.007	<.05	0.008	<.12	<.6	68
	Texas, Sprayberry	0.12	0.2	<3.9	<.01	<.01	0.6	0.026	<.18	<1.2	68
	Texas, Ward Estes N.	1.30	5.0	<2.6	0.7	<.008	<.04	0.06	<.13	2.4	68
SOUTH AMERICA	Venezuela, Ceuta	0.22	140.0	21.0	0.018	<.006	<.5	0.044	<.13	<.6	68
	Venezuela, Mesa	1.10	53.0	14.0	<.006	<.006	<.06	0.044	<.12	<.7	68
	Colombia, Orito	0.40	24.0	21.0	<.006	<.006	.08	0.006	<.12	1.5	68
MIDDLE EAST	Iran, Agha Jari	1.10	39.0	21.0	<.005	<.006	<.06	0.024	<.12	<.9	68
	Arabian Light (blend)	1.50	14.0	<9.6	<.008	<.01	<.09	0.012	<.16	<.4	68
	Kuwait Blend	2.90	29.0	9.0	<.005	0.8	<.5	0.005	<.14	<1.0	68
	Kuwait Blend	1.80	26.0	11.0	<.006	<.005	0.9	0.014	<.13	<1.4	68
	Middle East Blend	2.20	60.0	32.0	<.007	0.8	<.07	0.01	1.5	<1.2	68
AFRICA	Egypt, El Morgan	1.30	48.0	36.0	<.008	0.002	0.12	0.029	<.16	<.5	68
	Libya, Sarir	0.17	0.28	<4.0	<.008	<.008	<.06	0.05	<.13	<.5	68
ASIA	Indonesia, Duri	0.280	1.3	47.0	0.09	0.7	<.06	0.044	<.11	<.8	68
	Indonesia, Minas	0.06	0.1	16.0	<.01	<.007	<.07	0.006	<.11	<.8	68

TABLE 19 (Cont'd)

Region	State/Country and Field	Sulfur, Weight Percent	ppm V	ppm Ni	ppm As	ppm Ba	ppm Mn	Reference
NORTH AMERICA	Alaska, Nikiski	nd	62.3	79.5	0.037	0.3	6.39	69
	Alaska, Nikiski	0.13	0.358	nd	0.013	nd	0.026	69
	Alaska	2.00	0.447	nd	0.0006	0.047	0.023	69
	California, Wilmington	3.34	52	58.0	0.26	nd	0.045	69
	California	3.04	93.6	58.0	0.147	nd	2.11	69
	California	3.00	89.5	55.7	0.147	nd	2.47	69
	Louisiana, South Fields	0.38	0.778	nd	0.058	nd	0.249	69
	Texas, Clam Lake	0.227	0.22	3.04	0.106	0.078	0.019	69
	Texas, High Island	0.09	0.076	nd	0.031	0.104	0.043	69
	Texas, Smithbluff	0.147	0.058	nd	0.091	0.059	0.033	69
SOUTH AMERICA	Bolivia	0.031	0.0058	nd	nd	nd	nd	69
MIDDLE EAST	Abu Dhabi, Murban	1.01	0.118	nd	nd	nd	0.046	69
	Iran	2.40	40.9	13.6	nd	nd	0.021	69
AFRICA	Nigeria	0.21	0.435	nd	0.15	nd	1.29	69
ASIA	Indonesia, Katapa	0.0522	0.032	nd	0.042	nd	0.0053	69
	Indonesia, Katapa	0.061	0.0218	nd	0.074	nd	0.011	69

nd = not detected

TABLE 19 (Cont'd)

Region	State/Country and Field	Sulfur, Weight Percent	ppm					ppb				Reference
			V	Ni	Fe	Mn	Se	Cr	Sb	As	Hg	
NORTH AMERICA	California	1.590	100.6	199.0	79.65	1.31	0.765	12.34	44.035	516.9	114.0	70,71
	California	1.395	167.6	217.0	26.53	1.13	0.690	8.06	38.20	91.8	81.4	70,71
	California	0.920	4.0	137.5	16.84	1.01	0.151	7.87	51.13	62.9	88.2	70,71
	California	0.977	17.5	264.1	85.53	2.54	0.395	17.473	49.715	1112.4	29688.0	70,71
	California	2.387	121.5	152.9	59.51	0.73	1.396	9.144	68.8	111.7	77.83	70,71
	Louisiana	0.082	105.0	344.5	3.736	0.63	0.026	1.565	29.51	46.4	22.54	70,71
	Wyoming	2.467	298.5	112.9	5.78	0.91	0.321	8.715	71.75	111.1	76.75	70,71
AFRICA	Libya	0.469	8.2	49.1	4.938	0.79	1.096	2.302	55.2	77.3	2077.8	70,71
	Libya	1.203	7.6	76.5	120.84	1.15	0.236	15.280	106.8	151.7	62.39	70,71
	Libya	1.628	46.8	104.8	3.365	1.45	0.219	1.942	38.40	343.4	75.83	70,71
NORTH AMERICA	California, Casmalia			81						0.142		72
	Kansas-1			28						0.031		72
	Kansas-2			48						0.056		72
	Mississippi			<2						0.010		72
	Texas			<2						0.005		72
SOUTH AMERICA	Venezuela			<2						0.092		72
MIDDLE EAST	Mid East-1			109						0.03		72
	Mid East-2			22						0.021		72

TABLE 19 (Cont'd)

Region	State/Country and Field	ppm V	ppm Ni	Reference
MIDDLE EAST	Iraq, Ain Zalah	75	20	73
	Iraq, Ain Zalah	70	--	73
	Iraq, Ain Zalah	102	24.5	73
	Iraq, Ain Zalah	109	26	73
	Iraq, Bai Hassan	26.5	17.2	73
	Iraq, Bai Hassan	29.0	--	73
	Iraq, Bai Hassan	48	14.5	73
	Iraq, Jambur	9.0	--	73
	Iraq, Kirkuk	26.9	19.0	73
	Iraq, Kirkuk	34.0	16.6	73
	Iraq, Kirkuk	26.3	15.3	73
	Iraq, Kirkuk	--	13.8	73
	Iraq, Kirkuk	25.5	15.9	73
	Iraq, Kirkuk	25.0	16.7	73
	Iraq, Kirkuk	25.7	17.0	73
	Iraq, Kirkuk	26.0	18.0	73
	Iraq, Kirkuk	26.5	15.8	73
	Iraq, Kirkuk	47	22.9	73
	Iraq, Kirkuk	43	20.0	73
	Iraq, Kirkuk	44	20.3	73
	Iraq, Rumaila	35.4	13.6	73
	Iraq, Rumaila	13.6	--	73
	Iraq, Rumaila	10.6	--	73

TABLE 19 (Cont'd)

Region	State/Country and Field	ppm V	ppm Ni	Reference
	Iraq, Zubair	57.0	19.5	73
	Iraq, Zubair	15.0	8.9	73
	Iraq, Zubair	11.7	--	73
	Iraq, Zubair	19.6	--	73
	Iraq, Zubair	1.6	<0.7	73
	Iraq, Zubair	2.1	--	73

5. Shale Oil

The term oil shale covers a wide variety of fine-grained sedimentary rocks that contain organic material. Upon destructive distillation much of this organic material is released largely as an oil which is termed shale oil. The rock is only slightly soluble in organic solvents and frequently does not appear or feel oily. It is tough, elastic, resistant to fracture and has essentially no permeability or porosity(74).

The organic component of oil shale can be divided into 2 parts, a part that is soluble in organic solvents and a part that is not. It is the insoluble part, generally termed kerogen, which constitutes the bulk of the shale organic matter responsible for shale oil. The composition of kerogen varies considerably from shale deposit to deposit but it is thought to consist of largely cyclic polymeric material probably held together by cross linkages involving hetero atoms such as nitrogen, sulfur and oxygen(75).

There is no truly typical shale oil but shale oils have some properties in common. In general, most shale oils are black, waxy and possess high pour points. Relative to conventional crude oils, the nitrogen content of crude shale oil is high although the sulfur level is moderate.

Oil shales are widely distributed geographically. However, only certain deposits are considered to be sufficiently rich in kerogen to warrant commercial development. In the U.S. oil shale deposits are found in Tennessee and Nevada but the most important are in the

Green River Formation of Colorado, Utah and Wyoming. The Green River formation has received attention as a possible source of fuels. Within this formation, shale deposits underlie an area of 17,000 square miles in four basins: the Piceance Creek basin of Colorado, the Unita basin of Utah and the Washakie and Green River basins of Wyoming(75).

The energy potential of the Green River formation has been estimated to be more than 1 trillion barrels of oil with 600 billion coming from easily accessible, richer deposits which contain more than 25 gallons of oil per ton of shale(75). Shale deposits vary in accessability from those at the surface to very deeply buried shales in the Uinta basin. The outcrop called the Mahogany Ledge (because of its color) is the location of an experimental mine and consequently has been used to study mining and retorting methods. Most U.S. elemental shale oil analyses come from shale mined here. The oil shales of the Mahogany zone will probably be the first to be developed commercially.

Table 20 presents sulfur and nitrogen data of crude shale oil obtained from shale deposits throughout the world. While many of the samples were retorted using different techniques, it has been found that generally the retorting method utilized has relatively little effect on the characteristics of the oil produced unless extreme retorting conditions have been employed(76). Of the deposits listed, only the Green River can be considered to be a possible commercial source of fuels for consumption in the U.S. The others are included for the purposes of comparison.

TABLE 20

SULFUR AND NITROGEN CONTENT OF CRUDE SHALE OILS

Country	Formation/Location	Sulfur, weight per cent	Nitrogen, weight per cent	Reference
United States	Green River, Colorado	0.74	1.78	77
	Green River	0.69	2.13	78
	Green River	0.77	1.57	78
	Green River	0.51	2.10	78
	Green River	0.67	1.97	78
	Green River	0.72	1.73	78
	Green River	0.71	1.89	78
	Green River	0.64	1.95	79
	Green River*	1.10	1.73	79
	Green River	0.66	1.76	80
	Green River	0.59	1.96	81
	De Kalb County, Tenn.	3.38	0.88	78
Australia	Glen Davis, N.S.W.	0.56	0.52	78
Brazil	Paraiba Valley	0.41	0.98	79
China	Hwatien Mine, Manchuria	0.19	0.84	81
Estonia	Kukersite	1.10	0.10	82
France	Autun	0.51	0.90	78
	Severac	3.00	0.53	78
	Severac	3.40	0.65	78
	St. Hilaire	0.61	0.54	72
Israel	Um Barek	6.2	1.40	82
Lebanon	--	1.5	0.6	82
New Zealand	Orepuki	0.64	0.60	81
Scotland	--	0.35	0.77	77
South Africa	Boksburg, Transvaal	0.64	0.85	78
	Breyten, Transvaal	0.61	--	81
Spain	Puertollano	0.40	0.68	78
Sweden	Kvarntorp	1.65	0.68	78
Thailand	Maesod Area	0.41	1.10	81

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* Core drilling sample.

Crude shale oil derived from the Green River formation possesses an unusually high nitrogen level. It has been found that generally the nitrogen content is higher and the sulfur level lower in the higher boiling shale oil fractions. As of this writing, no metal content data for shale oil appear to be available in the published literature. An unpublished analysis by the Bureau of Mines of shale oil obtained from Green River shale indicates that this oil is high in iron and low in vanadium and nickel. The results obtained were: vanadium, 0 ppm; nickel, 4 ppm; and iron 67 ppm (83). Most of the metals were associated with the asphaltene fraction.

The nitrogen compounds present in shale oil are particularly troublesome in processing and must be removed before shale can be converted into useful liquid or gaseous fuels. Nitrogen removal can be accomplished by severe hydrogen treatment which also reduces the sulfur content to a low level.

6. Concluding Remarks

The sulfur and nitrogen content of crude oils consumed in the U.S. are well characterized by the available data while the levels of other trace elements are not. There are a number of factors which influence the availability and reliability of sulfur and nitrogen data. These include:

1. Knowledge of sulfur and nitrogen content of crude oils is used by oil companies to avoid poisoning catalysts and damaging refinery equipment, as a characterization tool, and as an aid in producing acceptable products. These analyses are performed on a routine basis by not only industry but also by the Bureau of Mines which makes this information available to the public.
2. The concentrations of nitrogen and especially sulfur are usually substantially higher than the levels of other trace elements.
3. Analyses of sulfur and nitrogen in a hydrocarbon matrix are relatively easy, classical procedures which yield accurate results with reasonable care. Little in the way of expensive laboratory apparatus is required.

These factors may be contrasted with those for the determination of the other trace elements. These data are quite sparse and of questionable accuracy because:

1. With the exception of vanadium and nickel, trace element analyses are not performed routinely by laboratories of most petroleum companies nor are they routinely performed by government laboratories.
2. These elements are present in very low concentrations, frequently as low as the parts per billion level.
3. Relatively new, frequently exotic and costly equipment is required to determine trace element content. Further, techniques to obtain analyses of trace elements contained in a hydrocarbon matrix have not been developed for most of the trace elements.

Rather than being routine, the determination of trace elements other than sulfur and nitrogen in crude oil is regarded as a research project. Analyses for these trace elements are expensive, will probably yield questionable results and, very significantly, have served no real purpose. However, a need for this type of analysis has recently been established since it is now recognized that many of the trace elements present in crude constitute a potential health and/or environmental hazard. This has initiated action on the part of Federal agencies as well as private industry to develop suitable referee analytical techniques for these elements. Once these techniques have been developed, they should be utilized first to analyze the most significant crudes such as those of the U.S. giant fields and those imported into the U.S. in quantity. These new data can fill today's informational void. Much of the data available today are not only questionable but many of the analyses have been performed on fields which are not longer significant contributors to the nation's crude oil needs.

Broadly speaking, the higher the concentration of an element the less its analysis will be affected by the many variables involved. The accuracy of existing sulfur and nitrogen data supports this generality. The data for vanadium and nickel are accurate on a qualitative basis although it appears that different methods produce somewhat different quantitative results. This is not surprising in view of the many sources of error possible in sample preparation, the analytical determination and the intrinsic limitations of the method itself. The values reported for other elements are of more questionable value

It is important to consider the state of the trace elements found in crude oils. Most sulfur is generally present in the form of a number of sulfur containing compounds which range from hydrogen sulfide gas to organic sulfur compounds such as mercaptans, disulfides and numerous sulfur containing ring compounds. Free sulfur is also present in certain crudes(84). Similarly, nitrogen is always associated with the hydrocarbon matrix in the form of a variety of compounds(85) some of which contain metals. The other trace elements can be considerably different. The metals, for example, may be bound to the hydrocarbon phase as is the case with chelate compounds; suspended as particulates in either the hydrocarbon phase or the water which is frequently emulsified with the crude; or dissolved in the aqueous phase. Consequently, one trace element can be present in four distinct forms.

One example of a multiphase element is iron which can be present in the hydrocarbon phase in relatively substantial quantities as a chelate. However, appreciable amounts of iron can be introduced into crude from adventitious sources, most frequently as rust particles. The latter can come from well piping, pipe lines, tankers and barges, storage tanks and refinery components.* Consequently, no samples, not even well head samples can be considered to be entirely free from iron contamination. This introduces yet another variable into the analysis of crude oil for iron and raises further suspicion on the results obtained. The addition of other elements in a similar manner can result in significant errors if the quantity inadvertently added is significant relative to the amount of that element initially present in the crude.

It is clear that trace element data require more than analytical precision if they are to be meaningful. Regardless of how accurately a given analysis has been performed, the usefulness of the information obtained depends upon how thoroughly the sample has been identified. The factors associated with complete identification include:

1. Meaningful designation of the sample analyzed. Descriptions such as "California" or "Middle East" are grossly inadequate.
2. The extent to which a sample is representative of its designation. The proper techniques for obtaining crude oil samples approach in sophistication the

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* Iron and other trace elements may be added inadvertently to the sample itself during the analytical procedure.

techniques of subsequent chemical analysis. For example:

- There are differences between "bottom hole" samples and those taken after the crude has been "stabilized" (i.e., after associated gas has been separated).
- There may be differences between a sample obtained from a discovery well and samples taken after the well or field is in production.
- Many wells have more than one producing horizon, and it is common for these different levels to possess differing trace element contents.
- Different wells from the same field may exhibit differences in oil quality because of limited porosity (i.e., because of incomplete "interconnection" of the oil in the reservoir). Thus, the analytical data from one well in a given field may not be representative of the entire field.
- Crude oil quality may vary as secondary and tertiary recovery methods are applied and, in the case of field samples, as additional wells are brought into production.

3. Whether the crude sample is from a field, a pipeline gathering system, a trunk pipeline or, in the case of foreign crudes, from a crude oil export terminal. Factors which influence the composition of the oil sample obtained include:

- The production volume of individual wells or fields may fluctuate on a day to day basis or vary over longer periods. This can affect the trace element content of pipeline blends when the production of a number of individual wells and/or several different fields is fed into a gathering system or trunk pipeline.
- Trunk pipelines may carry more than one crude oil "mix."
- Crude export terminals may supply more than one blend (e.g., Iranian "Light" and "Heavy") and the composition of these blends may vary with time. Consequently, the designation, "Iranian", is not sufficient nor is an analysis many years old if it is being applied to today's production.

The value of trace element data depends upon the way in which these data can be used. For crude oils, trace element data have been used to:

- Develop correlations useful in petroleum exploration.
- Determine in which refineries crudes can be processed.
- Determine the products that can be produced from a given crude.
- Contribute to establishment of a price for a given crude.

Elemental data, especially those of sulfur which are extensively available, have been utilized by firms in the petroleum industry to aid in the search for high quality crude oils. Petroleum companies have placed a top priority on finding and developing reserves of low crude oil which have high value in the world market. The sulfur level of crudes has been related by geologists to a number of factors(86,87), among them:

- Proximity of the oil reservoir to sulfate rocks such as anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$). Oil found in the vicinity of sulfate rock deposits is generally high in sulfur.
- Permeability of oil-bearing rocks and conditions permitting the underground flow of water.
- Geological age of the producing formation.
- Depth of the producing formation. Low sulfur crudes are rarely found above a depth of 4500 feet.

Other correlations have been developed for certain trace metals but these relationships are not nearly as well established as those for sulfur.

The ability to process different types of crude is frequently a necessity for coastal refineries that receive all or part of their crude supplies by tanker from foreign sources. These refineries are designed to process crudes with characteristics falling within a given range. Thus, a crude which possesses a sulfur level greater than can be accommodated by the hydrotreating capacity of a given refinery is usually not processed by that refinery. A crude with a high sulfur level that can be processed at only a limited number of refineries or that requires extensive, costly treating to remove unwanted elements can be regarded as an undesirable crude and will be priced accordingly.

A crude high in trace metals may find use primarily in asphalt production. A low sulfur, low trace element crude may be capable of being processed in a variety of ways to yield a number of different products. Because such a crude is versatile and does not require extensive treating to remove unwanted components, it could command a premium price in the world market.

The designation of a high quality crude (i.e., one which possesses very low levels of all hazardous and polluting trace elements) may be possible by examining out trace element data. Such designations must be used with caution and can only be based upon a complete set of data. For example, a number of coastal Texas and Louisiana fields possess very low concentrations of many trace elements. Similarly, the Cymric field in California possesses low levels of most trace elements but it has a very high level of mercury which relegates this crude to the less desirable category.

6.1 Correlations Indicated

Correlations indicated and conclusions drawn from the data and information presented herein are given below.

1. The sulfur and nitrogen levels of crudes consumed in the U.S. are well characterized while the levels for other trace elements are not.
2. Vanadium and nickel analyses are qualitatively correct but different methods of analysis produce somewhat different results. Values for other trace elements are more questionable.

3. Part (or even all) of the quantity reported for certain elements present in trace concentrations in a sample may have been introduced inadvertently by well piping, transportation systems, preparation of the sample for analysis, etc.
4. Analytical data on elements contained in crudes as suspended material or dissolved in associated water cannot have the same impact as data obtained from elements present as an intimate part of the organic matrix.
5. Samples must be completely identified as to their origin if data are to be meaningful.
6. Correlations have been developed between crude oil trace element concentrations and the geological occurrence of the oil. This is especially true for sulfur. These correlations may aid in locating crudes possessing low concentrations of trace elements.
7. The increasing demand for crude oil by the U.S. coupled with declining domestic production means that the developing crude oil gap will be met by imports.
8. Imports of crude from the Middle East can be expected to increase substantially. Imports from Canada and Venezuela already at high levels will change proportionaly less.
9. Crude from the Middle East is of lower quality than much U.S. production. The consumption of increasing quantities of Middle Eastern crude will decrease the overall quality of crudes processed in the U.S. This can require additional refining complexity in those refineries processing these crudes.

10. Trace element data are factors which contribute towards the establishment of a price for a given crude.

6.2 New Data Required

Based upon these conclusions it is apparent that a number of unmet needs exist related to crude oil trace element data. These unmet needs are listed below.

1. Far more extensive data are required for potentially hazardous elements present in trace concentrations in crude oil. This information should be obtained first on those crudes consumed in the greatest amounts in the U.S. Data from oil fields which can be expected to contribute to U.S. needs in the future (such as underdeveloped fields in the Middle East) would also be of value.
2. Referee methods must be developed in order to determine those trace elements that cannot be analyzed reliably at present. Several programs are underway to accomplish this. The methods developed should be widely promulgated as a first step in making crude oil trace element data more widely available.
3. It must be determined at which point a sample of oil should be obtained if the elemental analysis is to yield the maximum amount of information. In addition, it must be determined if it is desirable to remove extraneously introduced matter such as water and suspended particulates.

4. Further correlations should be developed between trace element data and geological information to aid in the search for high quality crude oils, i.e., those crudes possessing low levels of significant trace elements.

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E. TABLE OF CONVERSION UNITS

To Convert From	To	Multiply by
Barrels, oil	Cubic meters, oil	0.15899
Barrels, oil/day	Cubic meters, oil/day	0.15899
Feet	Meters	0.30480
Gallons/ton	Liters/metric ton	4.1726
Square Miles	Square kilometers	2.5900
Tons	Metric tons	0.90719

APPENDICES

SPECTROCHEMICAL ANALYSES OF COAL ASH FOR TRACE ELEMENTS *

ABSTRACT

The Bureau of Mines made spectrochemical analyses of ash from 827 U.S. commercial coals for barium, beryllium, boron, chromium, cobalt, copper, gallium, germanium, lanthanum, lead, lithium, manganese, molybdenum, nickel, scandium, strontium, tin, vanadium, ytterbium, yttrium, zinc, and zirconium. These 22 elements were detected in almost all of the ash samples examined. In addition, arsenic, bismuth, cerium, neodymium, niobium (columbium), rubidium, and thallium were detected in many samples.

INTRODUCTION

Interest in the trace element content of coal ash has resulted in a number of investigations, and a review of the literature was published in 1963 by the Bureau of Mines. The U.S. Geological Survey has continued to issue reports[5] giving basic information on the distribution of minor elements in various coal deposits of the United States, and Clark and Swaine[6] investigated trace elements in Australian coals. Most of the work cited consists of the intensive study of column samples of coal. The coal was separated from the free mineral matter in order that the elements in the coal could be used for geochemical evaluations.

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* Abernethy, R. F. et al., Bureau of Mines, R. I. 7281; July, 1969.

This study was made using coal as utilized in industry. The first interest by the Bureau in trace elements in coal was during the early years of World War II. Samples of coal ash were spectrographically examined for chromium, cobalt, nickel, and vanadium. These metals were scarce, and a source of supply was sought. The results of the tests were discouraging and were never published. The use of germanium in electronics set off a search for this element in coal.[7] Boron, phosphorus, sodium, potassium, and other elements have been found in fireside boiler tube deposits. More recently air pollution research has focused largely on sulfur and nitrogen oxides from the use of coal. In addition the presence of fluorine, chlorine, arsenic, beryllium, lead, and selenium was suspected; these elements are being found in varying amounts in the atmosphere.

In a cooperative undertaking by the Pittsburgh Coal Research Center at Pittsburgh, Pa., and the College Park Metallurgy Research Center at College Park, Md., the Bureau of Mines investigated the trace element content in ash of coals being used in industry. This report summarizes the semiquantitative spectrochemical analyses that show the occurrence of 29 trace elements in ash of commercial coals.

METHOD OF SAMPLE PREPARATION AND ANALYSIS

Tipple samples collected in connection with the purchase of coal by the Government and channel samples obtained for studies of coal preparation and coke making properties were selected for spectrochemical analysis of ash. The number of samples tested from each State is shown in figure 1, which gives the approximate location of the Eastern and Interior coal provinces where many of the samples were collected. Samples collected in the Western States were from three provinces, Northern Great Plains, Rocky Mountain, and Pacific Coast.

All laboratory samples of coal were prepared in accordance with the procedure described in Bureau of Mines Bulletin 638.[8] The coal samples were ashed at the Pittsburgh Coal Research Center by a low-temperature procedure designed to minimize loss of volatile elements.[9] A 10-gram sample of

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[8] Staff, Office of the Director of Coal Research. Methods of Analyzing and Testing Coal and Coke. BuMines Bull. 638, 1967, pp. 2-3.

[9] Page 49 of work cited in footnote 7.

pulverized coal was weighed into a flat-bottom dish 1.5 inches wide, 2 inches long, and 0.5 inch deep, fabricated from 36-gage aluminum sheet. The coal samples were ashed by heating slowly to 425° C in 4 hours and maintained at this temperature for 16 hours. The ash samples were transferred to small plastic bottles and sent to the College Park Metallurgy Research Center, where spectrochemical analyses were made according to the method described by Peterson and Zink.[10]

EXPLANATION OF TABLES AND DISCUSSION OF RESULTS

Semiquantitative spectrochemical analyses for 29 elements in the ash samples were coded on punch cards. Source of the samples by State, county, and bed was included. Several sets of averages for trace element content of the coal ashes were computed; these data are summarized in tables 1-6.

Table 1 gives the averages found for the element contents in ash of samples from the Eastern Province, the Interior Province, and the Western States. The crustal abundance and the approximate lower limit of detection are included to help interpret the average results. As some elements were not detected in all samples, the percentage frequency of detection is included. The first 22 elements listed were detected in most samples, and the results give an average value for the samples in which the element was detected. The last seven elements were not detected in many ashes, and a second average, given in parentheses, was calculated for the total number of samples examined, using zero for element content for the samples in which the element was not detected. The true average should be between these two values.

The results show that the average trace element concentration in coal ash, with a few exceptions, is greater than the crustal abundance, indicating that most of the elements detected are enriched in coal ash. An exception is manganese, which shows an average concentration that is less than the crustal abundance in ashes from all three areas. The average content of chromium, copper, nickel, and rubidium in ashes from the Western States also is less than the crustal abundance, but these elements are enriched in most of the ashes from the Eastern and Interior Provinces.

These data for 20 elements are shown in figure 2. The results for barium and strontium were omitted because some of their averages would extend beyond the graph.

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[10] Peterson, M. J., and J. B. Zink. A Semiquantitative Spectrochemical Method for Analysis of Coal Ash. BuMines Rept. of Inv. 6496, 1964, 15 pp.

Table 2 gives by geographical area the percentage of samples having trace elements in the various ranges of concentration. Some elements, such as beryllium, are found in a wide band of concentration covering six of 10 ranges, while others, such as zirconium, are in a very narrow band found in only three ranges. The table also shows changes in percentages of concentration in ranges by geographical area. The nickel content of Western States coals is less than that of Eastern and Interior Province coals.

Average trace element content in the ash of coals from each State is given in tables 3, 4, and 5 for the Eastern Province, Interior Province, and Western States, respectively. Only the 22 elements most often detected in ash are given in these three tables because the true average is uncertain for the seven elements that were detected in only a fraction of the samples.

The State averages for each area show considerable variation for some of the elements and give an indication of the range in content of the various elements detected in ash. Stadnichenko, Zubovic, and Sheffey,[11] in an interesting study of beryllium accumulation in coal, reported relatively high values for this element in certain coal deposits in Kentucky and Indiana. The State averages show a similar trend. The values for eastern and western Kentucky and for Indiana, ranging from 0.0015 to 0.0020 percent beryllium, are among the highest State averages found in the commercial coal ashes.

Average ash analyses for coalbeds where five or more samples from the same bed were analyzed are given for eight States in table 6. The coalbeds for each State are listed in descending geologic order.

This table illustrates again the variability of trace element content of coal ash. Averages for the Pittsburgh bed in Ohio, Pennsylvania, and West Virginia are fairly similar for many of the elements and show a trend that is slightly lower than the corresponding State average. On the other hand, averages for the Lower Kittanning bed in Ohio show a trend to slightly higher values than the State average for many of the elements, but in Pennsylvania and West Virginia this trend is not evident, and the bed average for an element may be greater or less than the corresponding State average.

To help interpret the average results, the tables show the number of samples tested from each area, and the average ash content computed from ash determinations made at 750° C according to ASTM specifications.[12]

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[11] Stadnichenko, Taisia, Peter Zubovic, and Nola B. Sheffey. Beryllium Content of American Coals. U.S. Geol. Survey Bull. 1084-K, 1961, pp. 253-295.

[12] American Society for Testing and Materials. Standard Methods of Laboratory Sampling and Analysis of Coal and Coke. D 271-68 in 1969 Book of ASTM Standards: Part 19, Gaseous Fuels; Coal and Coke. Philadelphia, Pa., 1969, pp. 19-20.

Individual analyses of ash for 25 elements are shown in table 7 for 781 samples with the source of coal arranged according to State, county, and bed. Forty-six samples included in the averages are omitted in the table because they represent either mixtures of coal from two or more beds, or a duplicate sample from a mine. Because of space limitations the individual determinations of bismuth, cerium, thallium, and ytterbium are not shown. According to the data in tables 1 and 2, bismuth, cerium, and thallium are not detected in many samples, and bismuth and thallium, when found, occur in relatively small quantities. Cerium, when detected, seldom occurs in amounts greater than the limit of detection of 0.02 percent. Ytterbium was detected in all ash samples tested, but the amount present rarely was greater than 0.001 percent.

In addition to the elements tabulated, silver was detected in all samples, and five other elements were found in a few samples as follows:

Element	No. of samples	Range, percent
Silver..................	827	<0.0001 to 0.0002
Cadmium.................	70	0.0002 to 0.01
Antimony................	44	0.002 to 0.01
Tungsten................	19	0.01 to 0.02
Cesium..................	10	0.005 to 0.01
Indium..................	2	0.001

SUMMARY

Spectrochemical analyses of ash from commercial coals show that 22 trace elements occur in most of the samples tested. Another seven elements--arsenic, bismuth, cerium, neodymium, niobium (columbium), rubidium, and thallium--were detected in many samples. For example, arsenic, with a limit of detection of 0.005 percent in ash, was found in 67 percent of the samples from the Eastern Province, 41 percent of those from the Interior Province, and 16 percent of the Western State ashes. Rubidium, with a limit of detection of 0.001 percent, was found in all samples from the Interior Province, but in only 58 percent of the ashes from the Western States.

All State averages for manganese content in ash are less than the crustal abundance. The average content of chromium, copper, nickel, and rubidium in ash of the Western State coals usually is less than the crustal abundance for each element; however, most of the ashes from the Eastern and Interior Provinces are enriched in these elements. Averages for the other elements generally show some enrichment in the ash.

TABLE 1. - Average trace element content in ash of coal from three areas,[1] percent

Element	Crustal abundance[2]	Approximate lower limit of detection[3]	Eastern Province		Interior Province		Western States	
			Frequency of detection	Average trace element content of ash	Frequency of detection	Average trace element content of ash	Frequency of detection	Average trace element content of ash
Barium	0.0425	0.002	100	0.0876	100	0.0399	100	0.1467
Beryllium	.00028	.0001	100	.0012	100	.0014	100	.0006
Boron	.0010	.0002	100	.0265	100	.0731	100	.0529
Chromium	.0100	.0001	100	.0230	100	.0224	100	.0066
Cobalt	.0025	.0020	100	.0184	98	.0193	98	.0097
Copper	.0055	.0001	100	.0128	100	.0089	100	.0047
Gallium	.0015	.0002	100	.0071	100	.0039	100	.0033
Germanium	.00015	.0003	99	.0048	100	.0104	95	.0017
Lanthanum	.0030	.01	92	.0145	86	.0131	81	.0128
Lead	.0013	.0001	100	.0055	100	.0131	100	.0029
Lithium	.0020	.0001	100	.0584	100	.0235	100	.0168
Manganese	.0950	.0001	100	.0260	100	.0325	100	.0212
Molybdenum	.00015	.0001	99	.0082	99	.0073	100	.0020
Nickel	.0075	.0001	100	.0209	100	.0262	100	.0054
Scandium	.0022	.002	100	.0089	100	.0069	97	.0052
Strontium	.0375	.001	100	.1052	100	.0658	100	.1456
Tin	.0002	.0001	100	.0019	99	.0019	100	.0017
Vanadium	.0135	.0001	100	.0336	100	.0325	100	.0152
Ytterbium	.00034	.0001	100	.0007	100	.0005	100	.0003
Yttrium	.0033	.001	100	.0142	100	.0118	100	.0076
Zinc	.0070	.005	98	.0230	100	.0743	93	.0258
Zirconium	.0165	.005	100	.0704	100	.0825	100	.0850
Arsenic	.00018	.005	67	.0159 (.0107)	41	.0119 (.0049)	16	.0073 (.0012)
Bismuth	.00002	.0001	82	.0002 (.0002)	77	.0001 (.0001)	83	.0001 (.0001)
Cerium	.0060	.02	31	.0238 (.0074)	11	.0214 (.0024)	13	.0238 (.0031)
Neodymium	.0028	.01	29	.0213 (.0062)	10	.0183 (.0018)	15	.0295 (.0044)
Niobium (columbium)	.0020	.001	73	.0053 (.0039)	88	.0055 (.0048)	85	.0053 (.0045)
Rubidium	.0090	.001	97	.0239 (.0232)	100	.0276 (.0276)	58	.0064 (.0037)
Thallium	.00005	.0005	43	.0019 (.0008)	49	.0008 (.0004)	9	.0005 (.00005)
Average ash..pct of dry coal	-	-	-	9.3	-	10.5	-	9.8
Number of samples	-	-	-	600	-	123	-	104

[1] Averages calculated for number of samples in which element was detected, except that averages in parentheses were calculated for all of the samples tested using zero for element contents below limit of detection.

[2] Mason, Brian. Principles of Geochemistry. John Wiley & Sons, Inc., New York, 3d ed., 1966, pp. 45-46.

[3] Peterson, M. J., and J. B. Zink. A Semiquantitative Spectrochemical Method for Analysis of Coal Ash. BuMines Rept. of Inv. 6496, 1964, pp. 8-10.

TABLE 2. - Percentage of samples in each range of trace element content of ash

Element and area[1]	Analysis of ash, percent										
	Not detected	<0.0001	0.0001 to 0.0002	0.0003 to 0.0007	0.0008 to 0.002	0.003 to 0.007	0.008 to 0.02	0.03 to 0.07	0.08 to 0.2	0.3 to 0.7	0.8 to 2.0
ELEMENTS OCCURRING IN MOST SAMPLES											
Barium:											
1..........	-	-	-	-	-	1	13	30	53	2	1
2..........	-	-	-	-	-	2	40	46	12	-	-
3..........	-	-	-	-	-	-	9	28	49	11	3
Beryllium:											
1..........	-	4	10	30	50	5	1	-	-	-	-
2..........	-	2	3	26	60	8	1	-	-	-	-
3..........	-	13	25	42	17	2	1	-	-	-	-
Boron:											
1..........	-	-	-	-	1	12	55	24	8	-	-
2..........	-	-	-	-	-	2	10	40	48	-	-
3..........	-	-	-	-	-	7	33	29	28	3	-
Chromium:											
1..........	-	-	-	-	1	3	72	23	1	-	-
2..........	-	-	-	-	1	1	72	26	-	-	-
3..........	-	-	2	1	19	38	40	-	-	-	-
Cobalt:											
1..........	-	-	-	-	-	8	77	14	1	-	-
2..........	2	-	-	-	1	9	77	6	5	-	-
3..........	2	-	-	1	1	33	61	2	-	-	-
Copper:											
1..........	-	-	-	-	3	21	72	4	-	-	-
2..........	-	-	-	-	9	29	62	-	-	-	-
3..........	-	-	2	4	33	39	22	-	-	-	-
Gallium:											
1..........	-	-	-	-	13	48	38	1	-	-	-
2..........	-	-	-	2	33	56	9	-	-	-	-
3..........	-	-	2	-	48	43	7	-	-	-	-
Germanium:											
1..........	1	-	-	7	38	29	24	1	-	-	-
2..........	-	-	-	-	13	24	60	3	-	-	-
3..........	5	-	1	30	51	10	3	-	-	-	-
Lanthanum:											
1..........	8	-	-	-	-	-	88	4	-	-	-
2..........	14	-	-	-	-	-	81	5	-	-	-
3..........	19	-	-	-	-	-	75	6	-	-	-
Lead:											
1..........	-	-	-	2	27	41	29	-	1	-	-
2..........	-	-	-	-	31	21	38	8	2	-	-
3..........	-	-	2	1	56	35	6	-	-	-	-
Lithium:											
1..........	-	-	-	-	-	6	35	26	33	-	-
2..........	-	-	-	-	2	40	39	10	9	-	-
3..........	-	-	-	4	10	36	34	12	4	-	-
Manganese:											
1..........	-	-	-	-	2	13	59	16	10	-	-
2..........	-	-	-	-	1	5	53	31	10	-	-
3..........	-	-	-	-	7	20	49	18	6	-	-
Molybdenum:											
1..........	1	-	1	2	27	24	44	1	-	-	-
2..........	1	-	-	-	16	41	41	1	-	-	-
3..........	-	-	5	17	65	9	4	-	-	-	-
Nickel:											
1..........	-	-	-	-	-	4	80	14	2	-	-
2..........	-	-	-	-	-	6	71	14	9	-	-
3..........	-	-	7	1	25	38	29	-	-	-	-
Scandium:											
1..........	-	-	-	-	1	40	58	1	-	-	-
2..........	-	-	-	-	6	59	33	2	-	-	-
3..........	3	-	-	-	14	63	20	-	-	-	-

See footnote at end of table.

TABLE 2. - Percentage of samples in each range of trace element content of ash--Continued

Element and area[1]	Analysis of ash, percent										
	Not detected	<0.0001	0.0001 to 0.0002	0.0003 to 0.0007	0.0008 to 0.002	0.003 to 0.007	0.008 to 0.02	0.03 to 0.07	0.08 to 0.2	0.3 to 0.7	0.8 to 2.0
ELEMENTS OCCURRING IN MOST SAMPLES--Continued											
Strontium:											
1..........	-	-	-	-	-	1	8	21	68	2	-
2..........	-	-	-	-	-	1	20	42	35	2	-
3..........	-	-	-	-	-	-	8	14	65	13	-
Tin:											
1..........	-	1	1	25	59	10	4	-	-	-	-
2..........	1	-	2	30	51	13	2	1	-	-	-
3..........	-	-	2	29	59	6	4	-	-	-	-
Vanadium:											
1..........	-	-	-	-	-	1	48	44	7	-	-
2..........	-	-	-	-	-	2	43	53	2	-	-
3..........	-	-	-	-	2	18	71	8	1	-	-
Ytterbium:											
1..........	-	-	13	45	42	-	-	-	-	-	-
2..........	-	1	39	43	16	1	-	-	-	-	-
3..........	-	1	59	34	6	-	-	-	-	-	-
Yttrium:											
1..........	-	-	-	-	1	15	77	7	-	-	-
2..........	-	-	-	-	4	35	55	5	1	-	-
3..........	-	-	-	-	9	42	49	-	-	-	-
Zinc:											
1..........	2	-	-	-	-	16	59	17	6	-	-
2..........	-	-	-	-	-	2	12	48	31	5	2
3..........	7	-	-	-	-	14	54	17	8	-	-
Zirconium:											
1..........	-	-	-	-	-	-	10	40	50	-	-
2..........	-	-	-	-	-	-	2	31	67	-	-
3..........	-	-	-	-	-	-	6	20	74	-	-
ADDITIONAL ELEMENTS FOUND IN MANY SAMPLES											
Arsenic:											
1..........	33	-	-	-	-	15	43	7	2	-	-
2..........	59	-	-	-	-	11	28	1	1	-	-
3..........	84	-	-	-	1	9	6	-	-	-	-
Bismuth:											
1..........	18	2	78	1	1	-	-	-	-	-	-
2..........	23	6	71	-	-	-	-	-	-	-	-
3..........	17	12	70	1	-	-	-	-	-	-	-
Cerium:											
1..........	69	-	-	-	-	-	23	8	-	-	-
2..........	89	-	-	-	-	-	10	1	-	-	-
3..........	87	-	-	-	-	-	10	3	-	-	-
Neodymium:											
1..........	71	-	-	-	-	1	21	6	1	-	-
2..........	90	-	-	-	-	-	10	-	-	-	-
3..........	85	-	-	-	-	-	12	3	-	-	-
Niobium (columbium):											
1..........	27	-	-	-	9	54	10	-	-	-	-
2..........	12	-	-	-	7	66	15	-	-	-	-
3..........	15	-	-	-	16	55	14	-	-	-	-
Rubidium:											
1..........	3	-	-	-	4	24	48	13	8	-	-
2..........	-	-	-	-	1	14	57	16	11	-	1
3..........	42	-	-	-	10	29	19	-	-	-	-
Thallium:											
1..........	57	-	-	7	29	5	2	-	-	-	-
2..........	51	-	-	33	15	1	-	-	-	-	-
3..........	91	-	-	8	1	-	-	-	-	-	-

[1] Area 1, Eastern Province, 600 samples.
Area 2, Interior Province, 123 samples.
Area 3, Western States, 104 samples.

TABLE 3. - Average trace element content in ash of coals from States in Eastern Province, percent of ash

Element	Alabama	Eastern Kentucky	Maryland	Ohio	Pennsylvania	Tennessee	Virginia	West Virginia
Barium......................	0.1195	0.1077	0.0450	0.0438	0.0703	0.1248	0.1273	0.0910
Beryllium..................	.0008	.0020	.0007	.0009	.0008	.0006	.0014	.0014
Boron......................	.0322	.0255	.0140	.0561	.0153	.0247	.0164	.0232
Chromium..................	.0207	.0260	.0140	.0235	.0244	.0200	.0253	.0222
Cobalt......................	.0198	.0212	.0150	.0144	.0175	.0136	.0182	.0202
Copper......................	.0150	.0156	.0075	.0080	.0125	.0116	.0171	.0132
Gallium....................	.0055	.0099	.0020	.0050	.0071	.0057	.0085	.0077
Germanium..................	.0046	.0064	.0007	.0059	.0049	.0035	.0041	.0046
Lanthanum..................	.0138	.0175	.0100	.0126	.0130	.0132	.0151	.0157
Lead........................	.0040	.0059	.0010	.0043	.0052	.0050	.0078	.0058
Lithium....................	.0812	.1064	.0140	.0394	.0642	.0994	.0441	.0520
Manganese..................	.0208	.0361	.0030	.0207	.0205	.0234	.0540	.0249
Molybdenum.................	.0117	.0071	.0017	.0057	.0098	.0080	.0106	.0073
Nickel......................	.0186	.0217	.0125	.0203	.0195	.0168	.0281	.0212
Scandium..................	.0078	.0131	.0065	.0058	.0086	.0141	.0092	.0093
Strontium..................	.1396	.1538	.0900	.0511	.0943	.1368	.1240	.1104
Tin.........................	.0024	.0063	.0005	.0013	.0011	.0019	.0030	.0017
Vanadium..................	.0338	.0400	.0225	.0236	.0330	.0354	.0417	.0348
Ytterbium..................	.0005	.0009	.0003	.0007	.0006	.0006	.0011	.0007
Yttrium....................	.0126	.0217	.0050	.0150	.0127	.0102	.0151	.0145
Zinc........................	.0243	.0203	.0200	.0284	.0222	.0242	.0291	.0201
Zirconium..................	.0607	.0823	.1100	.0805	.0680	.0460	.0559	.0738
Average ash..pct of dry coal	9.2	7.3	9.5	11.8	10.0	9.7	7.8	8.5
Number of samples..........	47	26	2	85	117	25	51	247

TABLE 4. - Average trace element content in ash of coals from States in Interior Province, percent of ash

Element	Arkansas	Illinois	Indiana	Iowa	Kansas	Missouri	Western Kentucky
Barium	0.1000	0.0423	0.0290	0.0300	0.0150	0.0183	0.0468
Beryllium	.0003	.0011	.0016	.0010	.0005	.0010	.0015
Boron	.0175	.0690	.0803	.0833	.0250	.0667	.0752
Chromium	.0300	.0252	.0182	.0400	.0150	.0433	.0197
Cobalt	.0550	.0131	.0226	.0343	.0450	.0233	.0167
Copper	.0055	.0071	.0091	.0067	.0150	.0108	.0095
Gallium	.0025	.0035	.0035	.0070	.0020	.0065	.0040
Germanium	.0010	.0116	.0139	.0133	.0060	.0088	.0082
Lanthanum	.0300	.0105	.0169	.0133	.0150	.0100	.0115
Lead	.0035	.0279	.0068	.0200	.0100	.0267	.0069
Lithium	.0100	.0386	.0231	.0300	.0050	.0137	.0171
Manganese	.0150	.0621	.0245	.0433	.0300	.0350	.0201
Molybdenum	.0125	.0075	.0049	.0100	.0050	.0108	.0079
Nickel	.0325	.0211	.0308	.0567	.0550	.0767	.0170
Scandium	.0040	.0077	.0074	.0050	.0040	.0047	.0067
Strontium	.2500	.0697	.0660	.0667	.0900	.0417	.0578
Tin	.0012	.0022	.0007	.0009	.0010	.0016	.0027
Vanadium	.0350	.0297	.0327	.0300	.0150	.0375	.0341
Ytterbium	.0003	.0004	.0004	.0008	.0003	.0009	.0005
Yttrium	.0060	.0089	.0098	.0100	.0275	.0142	.0142
Zinc	.0190	.1193	.0690	.1333	.0750	.0620	.0514
Zirconium	.0600	.0755	.0945	.0667	.0750	.0733	.0824
Average ash.........pct of dry coal..	8.3	11.7	10.6	15.5	10.5	12.4	9.3
Number of samples	2	29	31	3	2	6	50

TABLE 5. - Average trace element content in ash of coals from Western States, percent of ash

Element	Arizona	Colorado	Montana	New Mexico	North Dakota	Utah	Washington	Wyoming
Barium	0.0400	0.0795	0.3000	0.2250	0.2650	0.1122	0.1714	0.1967
Beryllium	.0010	.0006	.0012	.0008	.0002	.0003	.0004	.0028
Boron	.0500	.0494	.0475	.0361	.0337	.0861	.0314	.0417
Chromium	.0100	.0049	.0024	.0091	.0034	.0088	.0121	.0067
Cobalt	0	.0104	.0061	.0126	.0057	.0066	.0217	.0060
Copper	.0050	.0049	.0025	.0050	.0013	.0038	.0121	.0050
Gallium	.0050	.0032	.0039	.0034	.0020	.0030	.0059	.0017
Germanium	.0050	.0019	.0025	.0032	.0006	.0008	.0009	.0018
Lanthanum	0	.0129	.0097	.0150	.0096	.0131	.0133	.0050
Lead	.0040	.0031	.0038	.0040	.0022	.0024	.0025	.0007
Lithium	.0200	.0095	.0215	.0138	.0095	.0283	.0277	.0217
Manganese	.0100	.0216	.0456	.0165	.0300	.0157	.0121	.0160
Molybdenum	.0010	.0018	.0038	.0017	.0032	.0011	.0026	.0025
Nickel	.0050	.0053	.0026	.0069	.0014	.0051	.0114	.0047
Scandium	.0010	.0056	.0034	.0068	.0045	.0037	.0089	.0040
Strontium	.1000	.0974	.2612	.0800	.2612	.1457	.3071	.1167
Tin	.0010	.0023	.0009	.0016	.0013	.0013	.0009	.0012
Vanadium	.0100	.0125	.0097	.0213	.0094	.0117	.0429	.0167
Ytterbium	.0001	.0003	.0004	.0005	.0004	.0002	.0004	.0003
Yttrium	.0100	.0083	.0060	.0085	.0060	.0067	.0094	.0053
Zinc	.0100	.0362	.0337	.0164	.0250	.0109	.0243	.0425
Zirconium	.0400	.0872	.0612	.0914	.0662	.0861	.1286	.0450
Average ash..pct of dry coal.	9.7	9.2	12.6	11.8	12.0	7.0	12.7	8.7
Number of samples	1	40	8	14	8	23	7	3

TABLE 6. - Average trace element content in ash of coal from coalbeds where 5 or more samples were analyzed, percent of ash

State and bed	Average ash, percent of coal	No. of samples	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Ni	Pb	Sc	Sn	Sr	V	Yb	Y	Zn	Zr
Alabama:																								
Mary Lee	14.4	6	0.0167	0.1050	0.0003	0.0175	0.0183	0.0057	0.0067	0.0027	0.0125	0.1242	0.0120	0.0048	0.0175	0.0028	0.0080	0.0009	0.1167	0.0300	0.0005	0.0093	0.0125	0.0600
Black Creek	5.4	11	.0800	.1086	.0008	.0218	.0173	.0175	.0046	.0036	.0118	.0485	.0115	.0116	.0182	.0054	.0075	.0036	.1345	.0245	.0005	.0111	.0373	.0582
Illinois:																								
No. 6	11.4	13	.0800	.0468	.0009	.0171	.0262	.0088	.0043	.0105	.0100	.0536	.0685	.0080	.0265	.0178	.0053	.0025	.0623	.0362	.0004	.0062	.0708	.0800
No. 5	13.1	10	.0590	.0368	.0012	.0058	.0210	.0035	.0020	.0125	.0093	.0198	.0690	.0048	.0130	.0332	.0121	.0015	.0660	.0190	.0004	.0072	.1960	.0700
Indiana:																								
No. 6	9.7	7	.0843	.0243	.0013	.0157	.0190	.0089	.0034	.0126	.0129	.0171	.0421	.0026	.0171	.0079	.0064	.0010	.0443	.0329	.0003	.0064	.0457	.0900
No. 5	11.8	16	.0494	.0280	.0012	.0150	.0139	.0079	.0027	.0081	.0164	.0176	.0174	.0061	.0166	.0067	.0069	.0006	.0522	.0309	.0003	.0080	.0687	.0887
Kentucky (western):																								
No. 12	13.0	9	.0589	.0511	.0005	.0122	.0217	.0081	.0032	.0025	.0111	.0178	.0267	.0043	.0117	.0036	.0082	.0028	.0756	.0289	.0003	.0090	.0300	.0800
No. 11	7.3	18	.0894	.0406	.0012	.0153	.0222	.0095	.0045	.0073	.0106	.0204	.0189	.0101	.0169	.0034	.0071	.0044	.0567	.0364	.0004	.0098	.0411	.0850
No. 9	12.1	12	.0525	.0608	.0007	.0119	.0150	.0058	.0026	.0082	.0105	.0054	.0204	.0067	.0100	.0028	.0047	.0011	.0425	.0375	.0003	.0052	.0608	.0775
No. 6	5.8	8	.0887	.0400	.0047	.0306	.0187	.0154	.0048	.0156	.0157	.0259	.0182	.0091	.0312	.0235	.0054	.0017	.0662	.0312	.0009	.0410	.0887	.0825
Ohio:																								
Sewickley (No. 9)	13.7	11	.0545	.0591	.0005	.0085	.0236	.0055	.0037	.0023	.0136	.0645	.0125	.0023	.0136	.0028	.0071	.0011	.0482	.0209	.0006	.0088	.0148	.0773
Pittsburgh (No. 8)	11.5	20	.0565	.0285	.0006	.0074	.0245	.0052	.0039	.0036	.0105	.0345	.0152	.0029	.0148	.0029	.0051	.0014	.0405	.0240	.0006	.0076	.0128	.0650
Middle Kittanning (No. 6)	11.4	23	.0548	.0513	.0009	.0093	.0243	.0098	.0055	.0065	.0118	.0400	.0287	.0072	.0163	.0046	.0059	.0011	.0416	.0270	.0008	.0190	.0284	.0878
Lower Kittanning (No. 5)	11.8	9	.0631	.0450	.0020	.0478	.0194	.0118	.0057	.0098	.0175	.0311	.0241	.0091	.0522	.0071	.0067	.0008	.0578	.0256	.0009	.0256	.0456	.0789
Brookville (No. 4)	10.4	7	.0621	.0443	.0012	.0236	.0200	.0101	.0069	.0084	.0133	.0246	.0103	.0069	.0271	.0060	.0067	.0021	.0814	.0229	.0008	.0217	.0786	.0786
Pennsylvania:																								
Pittsburgh	10.6	12	.0308	.0729	.0006	.0132	.0212	.0067	.0042	.0038	.0130	.0424	.0240	.0049	.0150	.0040	.0078	.0013	.1300	.0367	.0005	.0096	.0148	.0842
Upper Freeport	10.8	29	.0112	.0755	.0007	.0162	.0252	.0114	.0060	.0054	.0108	.0666	.0172	.0124	.0159	.0055	.0077	.0010	.0934	.0272	.0005	.0117	.0234	.0572
Lower Freeport	10.1	10	.0074	.0730	.0007	.0225	.0275	.0133	.0075	.0069	.0136	.0890	.0173	.0155	.0250	.0038	.0088	.0007	.0780	.0320	.0007	.0118	.0256	.0505
Upper Kittanning	10.1	5	.0068	.0620	.0007	.0250	.0220	.0320	.0086	.0046	.0100	.1080	.0170	.0140	.0300	.0088	.0126	.0008	.0680	.0280	.0007	.0100	.0430	.0500
Lower Kittanning	8.6	30	.0125	.0607	.0008	.0169	.0250	.0133	.0085	.0043	.0127	.0846	.0139	.0094	.0207	.0063	.0091	.0011	.1057	.0353	.0007	.0138	.0186	.0737
Brookville	8.6	6	.0433	.0433	.0011	.0197	.0150	.0067	.0053	.0037	.0125	.0185	.0357	.0025	.0142	.0057	.0062	.0012	.0733	.0208	.0006	.0133	.0317	.0850
Virginia:																								
Splash Dam	6.7	8	.0212	.1100	.0013	.0156	.0350	.0160	.0097	.0058	.0175	.0662	.0277	.0075	.0275	.0087	.0104	.0033	.1337	.0437	.0011	.0152	.0269	.0650
Kennedy	6.6	5	.0200	.1740	.0012	.0210	.0210	.0170	.0076	.0045	.0140	.0400	.0676	.0124	.0220	.0066	.0052	.0023	.1400	.0400	.0009	.0130	.0168	.0620
Raven	6.9	6	.0133	.1667	.0019	.0167	.0367	.0250	.0103	.0040	.0133	.0333	.0917	.0150	.0350	.0105	.0097	.0055	.1083	.0483	.0012	.0183	.0188	.0383
West Virginia:																								
Redstone	8.3	15	.0383	.1087	.0007	.0086	.0267	.0079	.0061	.0046	.0121	.0271	.0487	.0075	.0137	.0046	.0073	.0015	.1140	.0260	.0006	.0083	.0119	.0700
Pittsburgh	8.8	43	.0448	.0970	.0005	.0112	.0240	.0061	.0050	.0042	.0106	.0367	.0343	.0080	.0135	.0050	.0058	.0017	.1126	.0241	.0006	.0098	.0116	.0828
Bakerstown	10.6	6	.0080	.0650	.0005	.0175	.0317	.0085	.0030	.0057	.0150	.0488	.0328	.0115	.0158	.0040	.0073	.0008	.0833	.0192	.0004	.0105	.0175	.0817
Upper Freeport	13.5	14	.0126	.0457	.0006	.0184	.0257	.0082	.0058	.0015	.0165	.0414	.0142	.0074	.0175	.0037	.0111	.0007	.0850	.0450	.0005	.0120	.0232	.0786
Upper Kittanning	10.5	9	.0211	.0444	.0011	.0183	.0302	.0167	.0122	.0038	.0150	.0381	.0211	.0128	.0367	.0081	.0128	.0012	.1056	.0483	.0009	.0108	.0238	.0589
Lower Kittanning	10.4	22	.0156	.0855	.0011	.0151	.0247	.0133	.0101	.0025	.0150	.0518	.0354	.0078	.0225	.0082	.0105	.0014	.0814	.0341	.0008	.0121	.0191	.0530
Stockton-Lewiston	8.5	5	.0140	.0440	.0018	.0116	.0120	.0120	.0056	.0017	.0160	.0740	.0044	.0012	.0200	.0028	.0062	.0010	.0760	.0380	.0006	.0130	.0084	.0720
Coalburg	10.5	5	.0130	.0760	.0010	.0130	.0160	.0110	.0066	.0011	.0160	.1060	.0086	.0070	.0150	.0036	.0102	.0009	.1100	.0500	.0005	.0086	.0070	.0620
Winifrede	9.5	7	.0229	.0900	.0061	.0136	.0254	.0257	.0153	.0041	.0129	.0743	.0104	.0041	.0429	.0143	.0104	.0023	.1000	.0371	.0012	.0197	.0092	.0571
Chilton	7.4	7	.0200	.0721	.0027	.0236	.0150	.0157	.0093	.0051	.0186	.0671	.0126	.0025	.0257	.0061	.0109	.0019	.1100	.0364	.0010	.0400	.0193	.1093
Cedar Grove	6.1	16	.0259	.0981	.0016	.0212	.0197	.0174	.0077	.0048	.0180	.0569	.0156	.0053	.0212	.0062	.0103	.0024	.1237	.0403	.0008	.0196	.0203	.0762
Campbell Creek	6.1	19	.0237	.1206	.0017	.0233	.0196	.0169	.0125	.0088	.0155	.0809	.0267	.0101	.0290	.0065	.0107	.0020	.1511	.0397	.0009	.0190	.0126	.0669
Eagle	6.2	13	.0138	.1115	.0038	.0338	.0204	.0175	.0085	.0063	.0162	.0600	.0202	.0040	.0243	.0041	.0108	.0029	.1407	.0364	.0006	.0159	.0272	.0746
Sewell	4.4	13	.0133	.1177	.0017	.0454	.0220	.0219	.0125	.0115	.0215	.0304	.0240	.0130	.0392	.0066	.0128	.0016	.1462	.0600	.0010	.0238	.0362	.0662
Pocahontas No. 4	5.9	5	.0066	.0560	.0012	.0380	.0160	.0170	.0032	.0020	.0190	.0548	.0046	.0050	.0166	.0052	.0096	.0026	.0720	.0440	.0006	.0200	.0370	.1120

See Figure 1

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APPENDIX

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash

(0 = below limit of detection)

State, county, and bed	Ash, per-cent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Alabama:																										
Bibb: Woodstock............	5.6	0.02	0.005	0.8	0.001	0.02	0.02	0.01	0.002	0.005	0.02	0.008	0.02	0.005	0.005	0	0.02	0.004	0.05	0.01	0.002	0.8	0.05	0.02	0.01	0.1
Jefferson:																										
America..................	11.2	.015	.005	.1	.001	.02	.02	.02	.005	.005	.015	.02	.01	.01	.005	0	.02	.005	.01	.005	.001	.08	.05	.02	.01	.1
Clements (top bench)......	13.6	.01	.003	.1	.0001	.01	.01	.01	.002	.0005	0	.1	.01	.02	0	.01	.01	.0008	.08	.002	.0002	.02	.02	.005	.01	.03
Clements (middle bench)..	8.5	.01	.005	.1	.0003	.01	.015	.01	.005	.0008	0	.08	.02	.02	0	.02	.015	.0005	.08	.01	.0005	.05	.03	.008	.01	.08
Clements (bottom bench)..	6.9	.02	.005	.1	.0005	.01	.015	.02	.005	.0015	0	.2	.01	.03	0	0	.02	.0008	.1	.005	.0003	.03	.05	.01	.01	.02
Mary Lee..................	11.7	0	.005	.08	.0005	.015	.02	.008	.008	.002	.01	.015	.02	.01	.005	0	.03	.001	.05	.01	.0008	.1	.05	.01	.02	.05
Pratt.....................	7.5	.02	.005	.05	.001	.015	.03	.02	.005	.005	.02	.01	.008	.005	.005	0	.01	.005	.02	.005	.001	.1	.02	.02	.01	.1
Do......................	7.0	.02	.002	.1	0	.002	.002	.02	.008	.008	.015	.2	.015	.001	0	.01	.005	.001	.02	.005	.003	.1	.015	.003	.005	.005
Do......................	14.0	.02	.005	.2	.0005	.02	.05	.02	.005	.005	.02	.01	.05	.01	.005	0	.02	.005	.02	.007	.001	.15	.05	.02	.02	.09
Do......................	8.1	0	.01	.1	.0005	.015	.05	.02	.005	.005	.01	.2	.03	.02	.002	.03	.03	.008	.05	.01	.002	.1	.1	.03	.015	.1
Marion:																										
Black Creek..............	12.9	.01	.02	.1	.0001	.01	.02	.02	.002	.003	.01	.15	.02	.01	0	0	.015	.0008	.1	.01	.0005	.1	.03	.01	.02	.03
Do......................	2.5	.01	.1	.1	.001	.02	.02	.02	.01	.002	.01	.02	.02	.02	0	.02	.03	.008	.015	.01	.01	.2	.02	.015	.03	.05
Do......................	5.2	.015	.1	.15	.0001	.02	.02	.02	.002	.003	.01	.05	.015	.015	0	0	.015	.001	.05	.005	.0005	.1	.02	.01	.02	.03
Do......................	10.0	.01	.05	.08	.001	.02	.02	.01	.005	.005	.015	.005	.01	.002	.005	0	.02	.003	.02	.005	.001	.15	.02	.01	.01	.1
Do......................	4.0	.05	.1	.1	.001	.05	.02	.01	.005	.005	.02	.008	.008	.005	.01	0	.02	.005	.01	.02	.003	.05	.02	.015	.06	.15
Do......................	2.5	.02	.1	.2	.0001	.02	.01	.02	.008	.003	.01	.05	.005	.015	0	.02	.015	.005	.01	.003	.01	.2	.015	.01	.03	.02
Do......................	2.7	.008	.1	.15	.001	.02	.015	.02	.005	.002	.01	.1	.01	.015	0	.02	.02	.008	.01	.005	.001	.2	.02	.01	.01	.03
Glen Mary................	3.4	.005	.1	.2	.0008	.02	.02	.02	.008	.001	.01	.08	.015	.01	0	.02	.02	.005	.01	.005	.008	.2	.02	.01	.03	.03
Shelby:																										
Montevallo...............	7.3	.005	.008	.1	.0002	.015	.05	.02	.005	.001	.01	.05	.05	.02	0	.02	.02	.005	.08	.008	.002	.2	.03	.01	.08	.02
Youngblood...............	2.7	.03	.02	.1	.001	.02	.02	.01	.008	.02	0	.01	.1	.02	0	0	.01	.008	.02	.003	.015	.1	.015	.005	.02	.03
Tuscaloosa:																										
Brookwood................	17.4	.005	.008	.1	.0001	.02	.02	.01	.005	.001	.01	.2	.02	.01	0	0	.02	.0008	.03	.015	.0005	.1	.03	.008	.01	.02
Do......................	17.0	0	.01	.08	.0001	.02	.02	.01	.008	0	.01	.15	.02	.015	.005	.03	.03	.005	.05	.01	.002	.1	.08	.01	.02	.08
Do......................	11.4	.01	.005	.08	.001	.02	.04	.02	.005	.002	.02	.01	.05	.008	.005	0	.02	.005	.01	.007	.001	.15	.05	.02	.005	.08
Clements.................	4.5	.01	.01	.1	.002	.02	.02	.02	.008	.01	.01	.1	.03	.05	0	.02	.02	.005	.08	.01	.001	.15	.05	.02	.02	.02
Milldale.................	11.3	.05	.02	.1	.0002	.02	.02	.02	.005	.001	.01	.1	.05	.02	0	.02	.03	.005	.05	.01	.005	.1	.03	.01	.08	.05
Do......................	5.3	0	.01	.15	.001	.02	.02	.02	.008	.005	.01	.08	.02	.015	0	.03	.02	.001	.005	.01	.0005	.15	.03	.015	.01	.03
Walker:																										
America..................	14.2	.03	.01	.2	.001	.02	.02	.02	.005	.001	.015	.02	.01	.005	.005	0	.02	.005	.02	.005	.001	.15	.02	.02	.02	.1
Do......................	15.1	.02	.05	.2	.0005	.02	.02	.02	.003	.002	.02	.03	.01	.01	.005	0	.01	.003	.05	.01	.002	.2	.03	.02	.01	.1
Black Creek..............	1.7	.01	.1	.1	.002	.02	.02	.02	.003	.01	.015	.025	.015	.02	.002	.05	.02	.003	.005	.01	.0002	.1	.05	.02	.05	.03
Do......................	5.5	.03	.1	.05	.0005	.03	.02	.02	.005	.005	.01	.02	.005	.01	.01	0	.02	.02	0	.005	.01	.1	.05	.002	.15	.1
Cobb.....................	10.5	.005	.02	.1	.0008	.01	.02	.01	.005	.002	.01	.2	.03	.015	0	.02	.02	.001	.02	.01	.0008	.1	.03	.008	.01	.05
Do......................	11.0	.01	.01	.2	.003	.02	.02	.02	.002	.005	.01	.15	.015	.02	.002	.02	.02	.0008	.05	.01	.0003	.1	.05	.01	.01	.03
Mary Lee.................	14.5	0	.015	.1	.0001	.015	.02	.008	.01	.002	.01	.3	.02	.005	0	0	.015	.005	.02	.01	.0008	.1	.03	.008	.015	.03
Do......................	15.8	0	.02	.1	.0001	.02	.01	.005	.01	.005	.01	.2	.015	.002	0	0	.01	.005	.05	.008	.001	.1	.03	.01	.02	.03
Do......................	16.3	.005	.01	.15	.0005	.02	.02	.005	.005	.005	.015	.02	.005	.001	.005	0	.02	.003	.02	.005	.001	.15	.02	.01	.01	.1
Do......................	15.1	.01	.03	.1	.0005	.02	.02	.005	.005	.001	.02	.01	.01	.001	.005	0	.02	.002	.02	.005	.001	.15	.03	.01	.005	.1
Do......................	12.7	0	.02	.1	0	.015	.02	.003	.002	.001	.01	.2	.002	.01	0	.02	.01	.001	.05	.01	.0008	.1	.02	.008	.005	.05
Winston:																										
Black Creek..............	9.2	.01	.01	.015	.0005	.01	.005	.003	.001	.0005	.01	.005	.003	.001	.003	0	.005	.001	.01	.005	.001	.08	.005	.005	.02	.05
Do......................	3.2	.01	.1	.15	.001	.02	.02	.03	.005	.0015	.01	.1	.015	.015	0	.02	.02	.005	.008	.005	.002	.2	.02	.015	.01	.05
Arizona:																										
Coconino: Unknown..........	9.7	0	.05	.04	.001	0	.01	.005	.005	.005	0	.02	.01	.001	.004	0	.005	.004	.004	.001	.001	.1	.01	.01	.01	.04
Arkansas:																										
Johnson: Lower Hartshorne.	4.0	.01	.03	.15	.0005	.1	.05	.001	.003	.001	.03	.01	.01	.01	.007	0	.05	.005	.005	.007	.002	.3	.05	.01	.03	.1
Logan: Paris...............	12.5	.01	.005	.05	.0001	.01	.01	.01	.002	.001	0	.01	.02	.015	0	.03	.015	.002	.015	.001	.0005	.2	.02	.002	.008	.02
Colorado:																										
Delta:																										
Lower "B"................	5.3	0	.3	.2	0	.01	.01	.01	.01	.0008	.01	.1	.1	.001	0	.03	.01	.008	0	.005	.002	.2	.02	.01	.015	.1
Unknown..................	4.7	0	.15	.1	.0005	.008	.002	.01	.003	.001	.01	.005	.01	.002	.005	0	.005	.003	.005	.002	.0008	.1	.02	.005	.15	.08
Do......................	6.5	0	.05	.1	.0005	.01	.002	.005	.005	.001	.015	.005	.015	.002	.007	0	.002	.004	0	.01	.001	.1	.01	.005	.005	.1
Do......................	7.4	0	.1	.15	.0005	.01	.005	.007	.003	.001	.02	.005	.01	.005	.01	0	.005	.003	.007	.01	.02	.1	.02	.009	.08	.1
Do......................	5.3	0	.09	.07	.0005	.008	.002	.002	.003	.0005	.01	.005	.002	.001	.005	0	.001	.004	0	.008	.001	.1	.003	.003	.005	.1

El Paso: Unknown	9.2	0	.01	.05	.0005	.005	.003	.001	.002	.001	.01	.005	.05	.001	.002	0	.001	.002	0	.01	.005	.07	.005	.005	.02	.05
Fremont:																										
Brookside	15.3	.01	.01	.08	.001	.01	.005	.005	.005	.001	.02	.002	.05	.001	.002	0	.003	.003	.002	.003	.0005	.15	.015	.015	.05	.1
Unknown	15.9	0	.005	.08	.0005	.008	.005	.001	.002	.0005	.02	.001	.08	.001	.01	0	.004	.002	0	.01	.001	.05	.01	.01	.02	.1
Do	17.5	0	.008	.1	.0005	.005	.002	.001	.002	.002	0	.002	.05	.001	.001	0	.001	.002	.005	.005	.001	.1	.008	.01	.01	.07
Do	8.6	0	.01	.1	.0005	.002	.002	.001	.002	.001	.01	.001	.02	.001	.005	0	.002	.002	0	.015	.001	.08	.005	.005	.05	.08
Do	9.1	0	.01	.05	.001	.01	.004	.005	.003	.001	.03	.002	.1	.001	.005	0	.005	.002	0	.002	.002	.15	.015	.015	0	.1
Do	7.8	.009	.04	.1	.001	.01	.005	.004	.002	.002	.01	.001	.05	.002	.005	0	.01	.002	0	.002	.0005	.15	.015	.015	.1	.05
Do	12.1	0	.005	.05	.0005	.02	.003	.001	.002	.0005	.01	.003	.05	.002	.002	0	.003	.0015	.002	.005	.001	.08	.01	.005	.015	.1
Do	10.1	0	.02	.05	.001	.015	.003	.002	.002	.001	.01	.002	.01	.001	.005	0	.001	.002	0	.01	.001	.08	.01	.01	.08	.1
Do	10.0	.005	.01	.05	.0008	.008	.004	.002	.002	.001	.01	.001	.05	.001	.002	0	.005	.002	0	.002	.01	.06	.01	.01	.02	.08
Do	6.4	0	.01	.05	.0005	.01	.002	.001	.001	.005	.01	.001	.008	.001	.005	0	.003	.001	0	.002	.0005	.03	.005	.005	.03	.06
Garfield:																										
Unknown	3.8	0	.1	.15	.0005	.005	.001	.003	.005	.0005	.01	.005	.005	.001	.005	0	.002	.005	0	.002	.002	.1	.01	.005	.01	.08
Do	9.8	0	.03	.1	.0002	.002	.001	.001	.003	.0005	0	.01	.008	.001	.002	0	.001	.002	.003	.006	.002	.1	.01	.002	.01	.07
Do	5.5	.005	.07	.1	.0002	.002	.001	.001	.003	.001	0	.005	.001	.001	.002	0	.001	.002	0	.01	.0015	.1	.001	.002	.1	.06
Gunnison: "E"	4.3	0	.3	.2	.0002	.015	.02	.01	.01	.001	.01	.02	.03	.02	0	.02	.02	.008	.005	.005	.005	.2	.03	.015	.015	.1
Huerfano: Unknown	8.4	.005	.01	.15	.0005	.01	.005	.01	.005	.002	.01	.005	.01	.001	.01	0	.005	.003	.01	.005	.001	.15	.02	.005	.02	.08
La Plata:																										
Unknown	5.2	0	.05	.02	.0002	.01	.002	.005	.002	.001	.01	.008	.002	.001	.005	0	.005	.002	0	.003	.0005	.04	.005	.005	.03	.05
Do	6.0	0	.05	.04	.0002	.015	.002	.005	.003	.002	.01	.008	.001	.001	.005	0	.005	.002	.002	.002	.001	.07	.01	.005	.05	.1
Do	8.2	.01	.05	.02	.0005	.008	.015	.01	.004	.004	.01	.005	.002	.002	.005	0	.005	.005	0	.003	.002	.1	.01	.005	.04	.1
Do	5.5	.005	.02	.02	.0005	.01	.01	.01	.003	.007	.01	.008	.002	.002	.005	0	.005	.002	.005	.01	.0005	.1	.02	.01	0	.1
Do	8.4	.005	.03	.03	.0008	.01	.005	.004	.002	.002	.01	.003	.005	.002	.005	0	.005	.0015	0	.008	.0005	.015	.005	.01	.01	.1
Do	2.9	.005	.02	.05	.0005	.01	.005	.002	.002	.005	.01	.005	.008	.002	.005	0	.005	.003	0	.005	.0005	.02	.005	.005	.02	.1
Do	7.3	.01	.05	.05	.0005	.02	.01	.015	.003	.015	.02	.01	.005	.002	.01	0	.01	.003	.02	.01	.001	.1	.02	.02	.05	.1
Do	6.7	0	.03	.05	.0002	.005	.005	.002	.002	.001	.01	.003	.009	.002	.005	0	.003	.003	0	.005	.004	.02	.005	.005	.02	.1
Las Animas:																										
Unknown	19.4	0	.008	.02	.0005	.02	.01	.008	.002	.002	.02	.05	.02	.001	.01	0	.01	.002	.01	.004	.0005	.1	.02	.01	.03	.09
Do	17.5	0	.005	.15	.001	.02	.005	.005	.001	.001	.01	.005	.01	.001	.005	0	.01	.001	.01	.005	.0005	.1	.02	.005	0	.1
Do	9.2	.005	.005	.15	.001	.02	.008	.015	.004	.002	.01	.01	.01	.002	.005	0	.01	.004	.001	.005	.001	.15	.02	.01	.005	.1
Do	19.2	0	.01	.02	.001	.02	.003	.005	.002	.002	.03	.002	.008	.001	.005	0	.01	.005	0	.005	.0008	.01	.02	.02	.01	.1
Do	14.9	0	.01	.01	.0008	.01	.005	.005	.002	.002	.008	.04	.02	.001	.01	0	.01	.002	.003	.001	.0005	.15	.01	.01	.004	.1
Mesa:																										
Unknown	13.2	0	.02	.08	.0005	.01	.005	.005	.005	.002	.02	.006	.01	.002	.01	0	.005	.003	.005	.01	.001	.05	.02	.005	.15	.1
Do	12.3	0	.03	.07	.0005	.004	.001	.002	.005	.001	0	.006	.004	.001	.005	0	.001	.003	0	.01	.002	.07	.005	.005	.02	.08
Moffat: Unknown	3.0	0	.1	.1	.0002	.01	.005	.005	.002	.0005	.01	.01	.003	.001	.005	0	.01	.002	0	.005	.002	.1	.01	.008	.02	.09
Montrose: Unknown	11.9	0	.02	.02	.0005	.02	.002	.005	.005	.001	.01	.005	.005	.002	.005	0	.01	.007	.01	.007	.008	.05	.02	.02	.03	.1
Routt: Wadge	8.5	0	.08	.1	.0005	.01	.003	.002	.002	.0005	.01	.01	.003	.001	.005	0	.002	.002	0	.003	.0005	.1	.003	.005	.03	.08
Weld: Unknown	6.1	0	.05	.1	.0002	.003	.008	.004	.002	.001	.01	.002	.03	.001	.002	0	.003	.01	.005	.003	.002	.3	.02	.005	.01	.04
Illinois:																										
Douglas: Murdock	13.5	.01	.05	.02	.0005	.01	.01	.005	.002	.005	.01	.02	.02	.001	.002	0	.008	.01	.02	.002	.0005	.3	.01	.005	.1	.05
Franklin:																										
No. 6	11.9	0	.05	.08	.0002	.01	.02	.005	.005	.002	0	.1	.1	.005	0	0	.015	.01	.05	.003	.005	.05	.02	.005	.1	.05
Do	8.6	.005	.05	.08	.0005	.015	.02	.01	.005	.005	0	.15	.1	.005	0	.02	.02	.01	.05	.005	.003	.1	.02	.005	.1	.05
Fulton:																										
No. 5	13.5	0	.04	.03	.001	.005	.02	.004	.001	.005	.008	.02	.05	.004	.008	0	.01	.02	.015	.002	.0001	.09	.01	.008	.5	.05
Do	11.9	0	.05	.01	.001	.005	.03	.004	.002	.007	0	.05	.1	.004	.005	0	.02	.07	.01	.003	.0007	.03	.02	.01	.1	.1
Do	11.8	0	.1	.02	.002	.002	.02	.003	.002	.02	.01	.02	.1	.004	.01	0	.01	.02	.02	.005	.004	.03	.03	.002	.1	.1
Do	12.7	0	.08	.1	.001	.005	.01	.004	.003	.009	0	.02	.1	.004	.005	0	.02	.08	.01	.05	.001	.05	.02	.01	.1	.1
Do	9.6	.008	.07	.008	.002	.007	.01	.005	.003	.02	.01	.003	.02	.005	.005	0	.01	.01	.02	.002	.001	.08	.02	.005	.4	.06
Do	10.6	.008	.05	.05	.002	.005	.02	.005	.002	.03	.01	.03	.07	.002	.008	0	.01	.02	.02	.003	.0005	.15	.015	.01	.3	.05
No. 6	10.6	.01	.08	.01	.002	.02	.02	.01	.005	.015	.01	.009	.05	.006	.008	0	.03	.01	.01	.008	.001	.05	.05	.008	.05	.1
Gallatin: No. 5	17.1	.01	.02	.02	.0005	0	.05	.002	.002	.01	0	.02	.05	.01	.004	0	.01	.1	.01	.001	.002	.04	.04	.004	.05	.04
Henry: No. 6	7.7	.005	.1	.04	.0015	.02	.02	.01	.005	.02	.01	.009	.02	.005	.005	0	.02	.05	.01	.005	.003	.05	.02	.005	.1	.1
Jackson: No. 6	8.3	0	.1	.1	.0001	.02	.05	.01	.005	.005	.01	.15	.03	.015	0	.02	.03	.01	.05	.01	.0015	.08	.05	.008	.05	.1
Logan: No. 5	16.8	0	.03	.05	.001	.008	.01	.002	.001	.005	.008	.02	.05	.003	.008	0	.01	.001	.015	.002	.0005	.1	.01	.008	.01	.05
Madison: No. 6	21.3	0	.03	.08	.0001	.015	.02	.008	.002	.005	.01	.02	.1	.02	0	.015	.01	.001	.05	.003	.0008	.08	.02	.003	.08	.05
Peoria:																										
No. 6	8.1	.01	.08	.008	.002	.02	.02	.015	.004	.02	.01	.008	.05	.01	.008	0	.03	.01	.02	.008	.002	.07	.05	.008	.09	.1
Do	7.3	.005	.1	.02	.0015	.02	.03	.01	.005	.02	.01	.007	.02	.005	.005	0	.02	.05	.01	.005	.002	.02	.03	.005	.1	.1
Randolph:																										
No. 6	17.1	0	.08	.02	.0005	.01	.02	.004	.002	.002	.01	.004	.05	.003	.008	0	.01	.001	.01	.005	.0005	.05	.03	.005	.05	.1
Do	11.9	0	.1	.02	.0005	0	.05	.002	.003	.01	0	.02	.05	.01	.004	0	.01	.005	.01	.001	.002	.04	.02	.004	.07	.02
Saline: Davis	12.7	0	.02	.08	.001	.015	.02	.008	.005	.008	.01	.05	.02	.02	0	.015	.02	.08	.08	.003	.005	.08	.02	.005	.1	.1
Sangamon: No. 5	16.3	0	.1	.07	.001	.01	.03	.004	.002	.009	0	.01	.1	.01	.005	0	.02	.007	.01	.05	.005	.02	.02	.01	.1	.1

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, percent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Illinois--Con.																										
Schuyler: No. 5	10.3	0	0.05	0.01	0.001	0.005	0.01	0.002	0.003	0.01	0.01	0.005	0.05	0.003	0.005	0	0.01	0.004	0.02	0.003	0.0005	0.07	0.005	0.005	0.3	0.05
Stark: No. 6	8.9	.01	.1	.02	.0015	.02	.03	.01	.008	.02	.01	.02	.1	.01	.005	0	.03	.05	.005	.005	.01	.02	.08	.01	.05	.1
Vermilion:																										
No. 6	19.1	0	.07	.05	.001	.015	.02	.01	.002	.005	.01	.05	.2	.005	.005	0	.1	.005	.015	.003	.001	.1	.05	.01	.3	.07
No. 7	9.1	0	.1	.05	.0015	.007	.02	.005	.003	.02	0	.05	.1	.005	.005	0	.01	.005	.02	.01	.003	.5	.02	.005	.05	.07
Williamson:																										
Davis and DeKoven	11.2	0	.05	.03	.001	.02	.03	.01	.005	.01	.02	.02	.01	.01	0	.02	.03	.05	.005	.003	.005	.02	.05	.03	.2	.08
No. 6	7.0	.01	.1	.08	.0005	.015	.02	.01	.005	.008	0	.15	.02	.005	0	.02	.02	.02	.05	.008	.001	.1	.03	.005	.05	.1
Indiana:																										
Clay:																										
Upper Brazil Block	19.4	.01	.08	.04	.001	.02	.02	.01	.002	.004	.01	.02	.04	.003	.005	0	.03	.004	.01	.004	.0003	.1	.02	.005	.1	.2
Do	4.5	0	.2	.02	.003	.1	.02	.02	.007	.04	.03	.01	.005	0	.005	0	.2	.01	.002	.01	.0007	.2	.02	.03	.04	.1
No. 3	7.2	0	.1	.02	.002	.01	.02	.015	.005	.005	.01	.008	.02	.005	.005	0	.02	.002	.01	.007	.0005	.05	.03	.03	.1	.08
Gibson: No. 5	13.1	.01	.05	.04	.001	.02	.01	.015	.005	.01	.01	.007	.02	.005	.005	0	.04	.01	.003	.01	.001	.1	.02	.008	.15	.1
Greene:																										
No. 4	7.8	.005	.1	.03	.005	.03	.01	.005	.005	.02	.02	.007	.01	.003	.01	0	.05	.01	.02	.005	.0005	.1	.02	.01	.05	.1
No. 5	8.7	0	.1	.04	.001	.01	.01	.01	.002	.008	.01	.02	.008	.003	.004	0	.02	.003	.02	.004	.0005	.02	.02	.005	.04	.1
Knox:																										
No. 5	9.2	0	.05	.01	.001	.015	.015	.02	.005	.005	.02	.005	.02	.01	.005	0	.02	.005	.008	.01	.0005	.1	.05	.02	.08	.1
No. 6	10.2	.005	.08	.05	.001	.01	.02	.01	.004	.02	.01	.015	.02	.002	.008	0	.01	.002	.01	.008	.001	.05	.05	.002	.04	.1
Owen: Upper Brazil Block	7.6	.01	.2	.07	.003	.1	.05	.02	.005	.02	.05	.02	.02	.007	.01	0	.1	.02	.01	.015	.001	.2	.05	.02	.1	.1
Pike:																										
No. 5	9.1	.01	.02	.05	.002	.02	.01	.008	.002	.01	.02	.005	.005	.003	.005	0	.02	.01	.02	.005	.0005	.1	.02	.01	.2	.1
Do	8.8	0	.05	.05	.002	.02	.01	.005	.003	.005	.02	.005	.01	.01	.005	0	.02	.002	.05	.01	.0005	.1	.03	.01	.05	.1
Do	8.5	0	.03	.005	.001	.015	.01	.005	.003	.005	.01	.005	.015	.01	.005	0	.01	.002	.01	.01	.0005	.08	.02	.008	.04	.08
Do	7.7	.015	.02	.02	.002	.015	.005	.005	.005	.015	.01	.005	.002	.002	.005	0	.01	.02	.02	.004	.0005	.05	.005	.01	.05	.07
Sullivan:																										
No. 5	10.4	0	.1	.05	.0015	.02	.05	.01	.002	.01	.02	.02	.01	.01	.005	0	.02	.002	.01	.01	.0005	.02	.1	.01	.05	.1
Do	11.1	0	.1	.05	.003	.04	.02	.01	.005	.02	.03	.1	.01	.01	.01	0	.05	.005	.01	.01	.0007	.1	.05	.01	.1	.1
No. 6	7.9	.005	.1	.03	.002	.02	.01	.005	.002	.015	.01	.005	.05	.005	.01	0	.015	.01	.02	.005	.0008	.05	.03	.005	.01	.1
Do	8.4	0	.1	.03	.001	.015	.03	.015	.003	.01	.01	.005	.05	.002	.005	0	.02	.008	.01	.005	.0015	.01	.05	.01	.05	.08
Do	9.1	.02	.2	.02	.002	.01	.03	.01	.005	.01	.02	.05	.05	.002	.005	0	.02	.01	.02	.01	.001	.1	.03	.01	.07	.1
No. 7	[illegible]	0	.2	.02	.002	.03	.02	.01	.005	.05	.01	.05	.02	.002	.005	0	.05	.01	.02	.007	.0015	.05	.05	.007	.1	.1
Vigo:																										
No. 3	[illegible]	0	.03	.02	.0015	.02	.05	.003	.005	.005	.02	.1	.05	.005	.005	0	.02	.005	.01	.01	.0005	.15	.05	.01	.03	.1
No. 5	25.5	0	.04	.02	.0005	.01	.01	.005	.001	.005	.01	.005	.05	.005	.005	0	.01	.002	.02	.005	.0005	.02	.02	.007	.05	.08
Do	14.0	0	.1	.02	.001	.005	.02	.005	.001	.005	0	.02	.05	.007	0	0	.01	.005	.02	.005	.0005	.03	.05	.005	.05	.07
No. 6	10.0	.02	.1	.01	.0015	.02	.02	.002	.002	.003	.02	.02	.1	.003	.002	0	.015	.01	.01	.005	.001	.02	.02	.01	.03	.1
No. 7	6.1	.01	.2	.06	.003	.04	.02	.01	.007	.07	.02	.1	.02	.007	.01	0	.1	.02	.02	.015	.001	.05	.05	.2	.2	.1
Warrick:																										
No. 5	13.2	.005	.03	.005	.0005	.015	.01	.001	.001	.002	.03	.005	.03	.004	.002	0	.005	.001	.01	.005	.0005	.02	.01	.002	.07	.08
Do	13.9	0	.02	.02	.0005	.005	.002	.002	.002	.005	.01	.005	.008	.002	.005	0	.005	.001	.008	.005	.001	.02	.015	.005	.05	.1
Do	11.0	0	.02	.01	.001	.01	.02	.02	.003	.01	.02	.02	.01	.01	.005	0	.01	.005	.03	.01	.001	.05	.05	.01	.05	.09
Do	12.4	0	.02	.02	.0005	.005	.01	.003	.001	.005	.01	.005	.02	.002	.005	0	.005	.002	.01	.002	.001	.02	.015	.005	.05	.08
Do	12.3	.005	.04	.03	.001	.015	.01	.003	.002	.01	0	.005	.01	.005	.005	0	.01	.007	.007	.006	.0005	.005	.02	.003	.02	.07
No. 6	13.0	.01	.05	.01	.0008	.015	.008	.01	.003	.01	.01	.005	.015	.002	.002	0	.02	.005	.01	.004	.001	.03	.03	.003	.07	.05
Do	9.2	.01	.05	.02	.001	.02	.015	.01	.005	.02	.01	.02	.01	.002	.005	0	.02	.01	.01	.008	.0005	.05	.02	.005	.05	.1
Iowa:																										
Appanoose: Mystic	10.8	.01	.1	.02	.001	.008	.02	.01	.005	.01	.01	.01	.03	.02	.005	0	.02	.02	.005	.005	.0008	.05	.05	.01	.2	.05
Marion:																										
Unknown	16.0	.01	.1	.05	.001	.015	.05	.005	.008	.01	.01	.03	.05	.005	.005	0	.05	.02	.005	.005	.001	.05	.02	.01	.1	.1
Do	19.7	.01	.05	.02	.001	.08	.05	.005	.008	.02	.02	.05	.05	.005	0	0	.1	.02	.005	.005	.001	.1	.02	.01	1.0	.05
Kansas:																										
Cherokee: Fleming and Mineral	9.2	0	.03	.01	.0005	.01	.01	.01	.002	.01	.01	.005	.05	.005	.005	0	.01	.01	.02	.003	.001	.08	.01	.005	.05	.05
Crawford: Weir-Pittsburgh	11.7	0	.02	.02	.0005	.08	.02	.02	.002	.002	.02	.005	.01	.005	.005	0	.1	.01	.01	.005	0	.1	.02	.05	.1	.1

Kentucky:																										
Bell:																										
Creech	11.4	0	.02	.05	.0005	.01	.01	.005	.003	.0005	.01	.03	.01	.001	.005	0	.008	.001	.01	.005	.0005	.05	.02	.005	.02	.05
Hance	9.4	.015	.03	.1	.0005	.02	.02	.005	.005	.001	.02	.1	.05	.002	.005	0	.02	.005	.05	.01	.0015	.1	.05	.03	.02	.15
Hazard No. 6	5.8	.02	.01	.1	.0005	.02	.02	.02	.02	.01	.02	.02	.1	.01	.005	.015	.02	.01	.02	.01	.005	.2	.05	.02	.05	.05
Hignite	2.6	0	.05	.05	.0005	.01	.02	.02	.008	.001	.01	.05	.02	.01	.005	.02	.02	.008	.005	.01	.02	.1	.05	.02	.05	.05
Mason	2.2	.01	.05	.1	.001	.02	.05	.02	.01	.02	.02	.015	.05	.05	.005	.05	.08	.008	.008	.05	.1	.1	.1	.05	.05	.1
Butler: No. 6	10.1	.08	.05	.05	.001	.05	.02	.01	.001	.01	.01	.1	.03	.015	0	.02	.02	.01	.05	.005	.005	.02	.02	.008	.1	.1
Daviess: No. 9	21.5	.005	.03	.02	.0005	.01	.01	.001	.003	.01	.01	.005	.01	.002	.005	0	.005	.005	.01	.005	.001	.02	.01	.005	.05	.05
Floyd: Elkhorn No. 3	5.7	.01	.05	.1	.003	.05	.03	.01	.003	.01	.02	.1	.08	.005	.005	0	.03	.005	.01	.01	.002	.3	.07	.03	.01	.1
Hopkins:																										
No. 6	4.1	.03	.08	.05	.002	.01	.01	.015	.005	.02	.02	.01	.008	.003	.005	0	.01	.02	.1	.005	.002	.15	.03	.02	.02	.09
Do	6.0	.01	.1	.02	.003	.05	.02	.02	.005	.02	.02	.02	.008	.002	.005	0	.02	.02	.02	.008	.001	.05	.05	.03	.15	.1
Do	4.3	.01	.1	.02	.005	.015	.01	.01	.003	.01	.01	.005	.05	.01	.005	0	.02	.02	.02	.005	.001	.05	.02	.02	.08	.1
Do	4.9	.02	.1	.03	.005	.02	.02	.02	.005	.015	.01	.01	.01	.008	.01	0	.03	.07	.05	.005	.0005	.1	.03	.02	.05	.1
Do	4.0	.02	.1	.05	.005	.015	.02	.02	.008	.02	.01	.01	.01	.01	.005	0	.03	.02	.05	.002	.001	.1	.05	.02	.03	.07
Do	1.9	.015	.15	.02	.015	.07	.02	.02	.01	.02	.03	.002	.01	.01	.005	0	.1	.02	.005	.008	.002	.01	.02	.2	.2	.05
No. 9	11.6	.005	.07	.1	.0005	.015	.02	.005	.002	.01	.01	.005	.05	.005	.005	0	.01	.001	.05	.005	.0005	.05	.05	.005	.05	.1
Do	9.4	0	.05	.1	.0005	.01	.02	.01	.002	.005	.01	.01	.03	.008	.005	0	.01	.002	.1	.005	.0005	.1	.08	.005	.03	.08
Do	16.0	0	.05	.15	.0005	.01	.01	.005	.002	.005	.01	.005	.01	.01	.005	0	.01	.005	.02	.005	.0002	.05	.03	.002	.1	.08
Do	9.4	0	.05	.02	.0005	.01	.01	.002	.002	.008	.01	.005	.02	.01	.005	0	.01	.003	.01	.003	.001	.01	.05	.005	.03	.07
Do	7.9	0	.1	.02	.002	.02	.01	.01	.003	.01	.015	.005	.01	.01	.005	0	.02	.002	.01	.005	.0005	.02	.02	.01	.08	.09
No. 11	7.4	0	.1	.05	.0005	.015	.05	.01	.008	.005	.01	.1	.1	.03	0	.02	.02	.01	.05	.008	.05	.08	.03	.008	.08	.08
Do	16.9	0	.06	.05	.0002	.01	.02	.008	.002	.002	.02	.01	.01	.005	.005	0	.01	.002	.02	.005	.001	.05	.02	.01	.05	.09
Do	5.9	0	.1	.05	.001	.01	.02	.01	.004	.005	.01	.005	.01	.01	.005	0	.01	.003	.05	.005	.005	.05	.03	.005	.05	.05
Do	6.6	0	.03	.05	.001	.015	.02	.01	.002	.003	.01	.005	.005	.005	.005	0	.015	.001	.01	.005	.0005	.02	.03	.005	.03	.08
Do	7.0	0	.08	.05	.001	.02	.01	.005	.002	.008	.01	.008	.003	.007	.005	0	.01	.002	.05	.005	.001	.1	.02	.005	.03	.07
Do	5.3	0	.1	.03	.0005	.02	.02	.005	.005	.002	.01	.005	.02	.005	.005	0	.02	.002	.02	.005	.001	.05	.05	.01	.01	.09
Do	6.7	0	.07	.05	.001	.01	.02	.01	.005	.01	.01	.015	.03	.01	.005	0	.015	.005	.1	.005	.001	.1	.05	.01	.03	.1
Do	6.4	0	.1	.03	.002	.02	.03	.01	.003	.01	.01	.005	.02	.01	.005	0	.01	.003	.02	.008	.003	.1	.04	.01	.02	.1
Do	6.2	0	.1	.03	.001	.01	.01	.003	.005	.01	.01	.01	.005	.01	.005	0	.01	.005	.02	.002	.001	.08	.015	.01	.07	.07
Do	6.3	0	.1	.08	.001	.015	.02	.01	.002	.005	.01	.005	.02	.01	.005	0	.015	.002	.08	.008	.001	.05	.02	.01	.04	.08
No. 12	13.5	0	.06	.05	.001	.015	.02	.01	.003	.002	.01	.01	.03	.01	.005	0	.01	.001	.05	.01	.0005	.08	.03	.005	.03	.06
Do	13.3	0	.05	.08	.0005	.01	.02	.01	.002	.002	.01	.005	.04	.002	.005	0	.01	.001	.1	.008	.001	.1	.03	.01	.02	.08
Do	15.6	0	.05	.07	.0008	.01	.02	.005	.002	.0015	.01	.005	.04	.002	.01	0	.01	.005	.1	.005	.005	.1	.02	.003	.02	.08
Knott:																										
Hazard No. 4	8.6	.005	.015	.1	.0015	.02	.02	.01	.03	.015	.015	.2	.02	.002	.008	.2	.03	.01	.03	.01	.005	.15	.05	.02	.015	.1
Hazard No. 7	4.4	0	.05	.08	.0015	.03	.05	.02	.015	.01	.02	.15	.02	.01	.008	.05	.02	.008	.005	.015	.001	.15	.05	.02	.01	.05
Do	9.1	0	.02	.15	.0008	.01	.02	.01	.005	.001	.02	.15	.05	.001	.005	0	.01	.005	.007	.01	.005	.15	.05	.01	.01	.08
Letcher:																										
Elkhorn No. 3	6.2	.01	.02	.2	.002	.02	.015	.015	.007	.002	.03	.1	.007	.005	.005	0	.015	.003	.01	.01	.002	.2	.03	.05	.02	.2
Hazard No. 4	4.5	.01	.05	.1	.0015	.05	.02	.015	.005	.003	.03	.1	.007	.005	.005	0	.02	.003	.01	.01	.001	.2	.05	.05	.01	.15
Martin: Pond Creek	8.4	.01	.05	.1	.002	.01	.02	.005	.005	.008	.03	.1	.02	.003	.01	0	.015	.001	.01	.01	.001	.1	.03	.02	.02	.1
Muhlenberg:																										
No. 9	12.2	.01	.08	.05	.0005	.02	.02	.005	.005	.01	.01	.005	.02	.005	.005	0	.01	.005	.02	.005	.005	.02	.05	.01	.1	.09
Do	11.9	0	.03	.02	.0005	.005	.01	.002	.002	.01	.01	.005	.01	.005	.005	0	.005	.001	.02	.003	.0005	.02	.03	.005	.05	.07
No. 11	6.5	0	.1	.05	.001	.015	.02	.01	.008	.01	.01	.1	.03	.02	0	0	.02	.005	.08	.01	.002	.02	.03	.008	.08	.1
Do	7.4	0	.07	.02	.002	.02	.02	.015	.005	.01	.01	.02	.01	.01	.01	0	.02	.002	.02	.007	.002	.05	.05	.01	.05	.1
Do	6.8	.005	.1	.03	.002	.015	.02	.005	.005	.01	.01	.005	.01	.005	.005	0	.02	.001	.05	.01	.001	.05	.05	.005	.04	.1
Do	7.6	0	.1	.02	.001	.015	.02	.01	.005	.002	.01	.005	.02	.01	.005	0	.02	.002	.03	.009	.002	.03	.05	.01	.04	.1
Do	6.4	0	.1	.06	.002	.02	.04	.01	.003	.01	.01	.005	.02	.01	.01	0	.02	.002	.1	.01	.002	.08	.07	.02	.02	.1
Do	5.5	0	.1	.05	.0015	.02	.01	.01	.005	.01	.01	.005	.008	.005	.005	0	.02	.002	.02	.01	.002	.05	.02	.01	.02	.08
Do	7.7	0	.1	.03	.0015	.015	.03	.02	.008	.01	.01	.05	.01	.01	.005	0	.03	.008	.005	.01	.003	.01	.05	.02	.05	.08
No. 12	13.3	0	.1	.05	.0001	.02	.03	.01	.005	.005	.01	.1	.03	.015	.005	.02	.02	.01	.05	.01	.01	.05	.02	.01	.08	.1
Do	12.2	.005	.05	.03	.0005	.01	.015	.005	.002	.002	.01	.005	.01	.001	.008	0	.005	.001	.08	.005	.001	.08	.02	.005	.04	.08
Do	11.5	.005	.07	.05	.0005	.01	.02	.005	.003	.002	.01	.005	.05	.002	.005	0	.01	.002	.1	.01	.0005	.1	.03	.008	.01	.08
Do	13.6	0	.02	.05	.0005	.01	.02	.01	.002	.002	.01	.005	.01	.001	.005	0	.01	.001	.1	.008	.001	.02	.03	.01	.02	.07
Do	12.7	0	.05	.07	.0005	.01	.02	.01	.002	.001	.01	.005	.02	.001	.005	0	.01	.001	.08	.008	.001	.1	.03	.01	.02	.07
Do	11.5	.005	.08	.02	.0005	.015	.03	.008	.008	.005	.02	.02	.01	.005	.005	0	.02	.01	.005	.01	.005	.05	.05	.02	.03	.08
No. 13	9.3	.02	.08	.05	.002	.02	.02	.02	.005	.01	.02	.03	.005	.01	.005	0	.03	.01	.05	.02	.002	.07	.05	.02	.05	.08
Ohio:																										
No. 6	11.0	.01	.03	.08	.0015	.015	.03	.008	.002	.01	0	.05	.02	.015	0	.01	.02	.008	1.0	.005	.0008	.05	.03	.01	.08	.05
No. 9	8.3	0	.07	.03	.001	.01	.03	.005	.002	.01	.01	.005	.02	.01	.005	0	.01	.002	.05	.005	.0015	.07	.02	.003	.02	.07
Do	17.2	0	.03	.02	.0005	.008	.01	.005	.003	.008	0	.005	.01	.005	.005	0	.005	.001	.01	.001	.0005	.03	.01	.003	.1	.06
No. 11	9.3	.005	.1	.03	.002	.01	.02	.01	.004	.01	.01	.01	.01	.01	.005	0	.02	.005	.02	.005	.0005	.05	.03	.01	.03	.06
Perry: Hazard No. 9	9.5	0	.02	.05	0	.015	.02	.02	.01	.001	.01	.2	.01	.003	0	.02	.01	.005	.01	.005	.003	.2	.02	.005	.015	.03

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, per-cent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Kentucky--Con.																										
Pike:																										
Clintwood	8.1	0.005	0.01	0.1	0.0015	0.03	0.02	0.02	0.005	0.003	0.015	0.2	0.008	0.002	0.01	0	0.02	0.002	0.01	0.01	0.0015	0.1	0.02	0.01	0.02	0.1
Elkhorn No. 1	9.1	.01	.02	.1	.001	.02	.03	.02	.01	.005	.02	.2	.02	.01	.005	.05	.02	.008	.08	.02	.0005	.15	.05	.02	.01	.05
Do	8.3	.01	.02	.06	.002	.015	.05	.02	.02	.01	.02	.03	.05	.002	.005	0	.02	.01	.06	.02	.003	.1	.05	.02	.015	.05
Elkhorn No. 2	6.9	0	.005	.2	.0001	.015	.01	.01	.005	.002	.01	.1	.02	.002	0	.02	.01	.002	.2	.005	.0008	.2	.02	.01	.01	.05
Do	6.8	.005	.01	.2	.001	.01	.02	.01	.01	.01	.02	.02	.1	.01	.005	.02	.015	.01	.01	.02	.001	.1	.05	.02	.05	.05
Elkhorn No. 3	4.6	.05	.05	.06	.002	.015	.05	.02	.02	.02	.02	.02	.03	.015	.01	0	.05	.01	.02	.02	.005	.1	.02	.02	.02	.1
Lower Elkhorn	9.8	.005	.008	.1	.0001	.015	.015	.01	.005	.0015	.01	.1	.02	.002	0	.02	.01	.0008	.15	.01	.001	.2	.02	.01	.008	.02
Williamson	8.0	.01	.01	.1	.008	.02	.02	.01	.008	.002	.01	.1	.02	.015	0	.02	.01	.008	.08	.005	.0005	.2	.02	.01	.005	.08
Williamson (top bench)	6.2	.005	.02	.2	.001	.03	.05	.02	.01	.01	.015	.2	.1	.008	.005	.08	.03	.008	.02	.015	.001	.3	.05	.02	.01	.1
Winifrede	5.2	0	.02	.1	.008	.02	.01	.02	.01	.01	.01	.1	.01	.002	0	.03	.01	.003	.008	.008	.0005	.2	.03	.015	.005	.1
Do	6.0	0	.03	.1	.01	.05	.05	.05	.02	.01	.02	.1	.1	.005	.008	.08	.02	.01	.01	.02	.001	.15	.02	.05	.005	.1
Union:																										
No. 9	9.5	0	.02	.1	.0005	.01	.01	.01	.002	.005	.01	.005	.005	.005	.005	0	.01	.002	.01	.005	.001	.1	.05	.005	.05	.07
Do	9.8	0	.05	.1	.0005	.015	.02	.01	.003	.008	.01	.005	.05	.005	.005	0	.015	.005	.02	.005	.001	.02	.05	.005	.07	.1
Webster:																										
No. 14	9.0	.02	.1	.02	.001	.02	.02	.01	.01	.01	.01	.005	.01	.005	.005	0	.02	.015	.005	.005	.001	.03	.02	.02	.05	.1
Do	7.5	0	.1	.03	.001	.02	.02	.008	.003	.01	.01	.02	.02	.005	.005	0	.02	.002	.015	.01	.001	.05	.02	.02	.02	.1
Maryland:																										
Allegany: Pittsburgh and Tyson	10.4	0	.008	.05	.0005	.01	[illegible]	.005	.002	.0005	.01	.008	.001	.001	.005	0	.005	.001	.005	.005	.0005	.08	.015	.005	0	.07
Garrett: Upper and Lower Kittanning	8.6	.01	.02	.04	.001	.02	[illegible]	.01	.002	.001	.01	.02	.005	.003	.01	0	.02	.001	.02	.008	.0005	.1	.03	.005	.02	.15
Missouri:																										
Henry: Tebo	11.8	0	.1	.02	.0015	.01	.05	.01	.005	.01	0	.02	.02	.02	.002	0	.1	.02	.005	.005	.002	.05	.07	.01	.05	.08
Macon: Bevier	10.1	.01	.1	.02	.001	.02	.05	.01	.02	.005	.01	.02	.02	.01	.005	0	.05	.01	.005	.005	.001	.02	.03	.02	.005	.08
St. Clair: Tebo	12.8	0	.05	.02	.001	.08	.05	.01	.003	.01	0	.02	.02	.01	.005	0	.1	.02	.005	.005	.002	.05	.05	.01	.2	.08
Vernon:																										
Mineral	12.2	0	.05	.02	.001	.01	.05	.015	.005	.01	.01	.01	.05	.01	.002	0	.1	.05	.005	.005	.003	.05	.05	.02	.75	.05
Do	14.5	0	.05	.02	.001	.01	.05	.015	.005	.01	0	.01	.05	.01	.002	0	.1	.05	.005	.005	.001	.03	.02	.02	.05	.1
Montana:																										
Big Horn: Unknown	4.2	0	.02	.5	.0001	.005	.002	.002	.002	.008	0	.005	.01	.005	0	.02	.002	.008	.005	.003	.0008	.09	.01	.002	.05	.02
Custer: Unknown	12.8	0	.1	.5	.002	.007	.005	.004	.002	.0005	.01	.02	.2	.001	.005	0	.004	.004	0	.004	.0007	.7	.01	.005	.1	.1
Dawson:																										
Unknown	16.9	0	.08	.2	.0005	.005	.001	.001	.005	0	.01	.05	.02	.001	.005	0	.001	.005	.001	0	.002	.2	.005	.005	.01	.07
Do	19.3	0	.08	.5	.0005	.01	.002	.002	.005	0	.01	.05	.05	.001	.005	0	.001	.005	.001	.005	.001	.2	.01	.005	.02	.1
Garfield: Unknown	16.8	0	.05	.1	.0005	.002	.005	.005	.005	.002	.01	.02	.05	.01	.005	0	.01	.005	.005	.005	.0015	.2	.02	.01	.05	.1
Park:																										
Unknown	13.6	0	.01	.2	.005	.008	.002	.001	.01	.001	.01	.02	.005	.002	.005	.02	.002	.001	0	.003	.001	.2	.008	.008	.01	.02
Do	7.2	0	.01	.2	.0005	.008	.002	.005	.002	.001	.01	.005	.01	.01	.002	.02	.002	.001	.003	.002	.0005	.2	.01	.008	.01	.02
Richland: Unknown	10.0	0	.03	2.0	.0002	.004	.001	.001	.001	0	.008	.002	.02	.001	.002	0	.001	.002	0	.002	.0008	.3	.005	.005	.02	.06
New Mexico:																										
Colfax:																										
Sugarite	18.1	.006	.02	.02	.0005	.005	.01	.005	.004	.003	.01	.02	.01	.002	.005	0	.005	.002	.001	.008	.008	.02	.05	.005	.02	.1
Yankee	23.3	0	.005	.8	.0005	.02	.01	.003	.002	.002	.01	.001	.003	.003	.005	0	.005	.002	.005	.005	.002	.05	.02	.01	.008	.09
Do	15.3	0	.01	.03	.0005	.01	.005	.003	.003	.002	.01	.001	.005	.001	.005	0	.005	.002	0	.003	.001	.08	.02	.01	.007	.1
Do	12.6	0	.01	.8	.001	.005	.07	.005	.005	.005	.03	.005	.01	.002	.002	.03	.005	.02	.005	.01	.002	.03	.04	.01	.01	.05
Do	12.9	0	.02	.2	.001	.02	.01	.005	.004	.005	.04	.002	.01	.002	.01	0	.01	.004	.01	.01	.0005	.1	.05	.02	.01	.1
McKinley: Aztec	16.3	0	.03	.05	.0001	.008	.015	.008	.008	.002	.01	.015	.03	.002	0	.02	.008	.008	.008	.005	.002	.05	.02	.01	.01	.1
Rio Arriba:																										
Unknown	10.9	0	.02	.05	.0005	.01	.01	.005	.002	.001	.01	.005	.01	.002	.005	0	.005	.001	0	.005	.0005	.02	.01	.01	.005	.1
Do	14.3	.005	.03	.1	.001	.015	.01	.005	.003	.002	.02	.005	.01	.002	.005	0	.005	.002	0	.005	.0005	.01	.01	.01	.02	.1
Sandoval: Kaseman	5.9	0	.07	.1	.0005	.005	.005	.001	.001	.0005	.01	.005	.01	.002	.005	0	.005	.0005	0	.002	.0002	.08	.003	.002	.05	.06

San Juan:																										
Unknown	2.9	0	.08	.05	.0001	.008	.004	.005	.002	.0005	.01	.02	.008	.001	.005	0	.002	.002	0	.005	.002	.1	.005	.002	0	.08
Do	5.3	.01	.05	.05	.0005	.015	.005	.01	.002	.005	.01	.05	.01	.001	.005	0	.008	.0003	.005	.005	.001	.1	.02	.005	.02	.1
Do	7.3	0	.08	.05	.0005	.01	.003	.002	.005	.002	.01	.01	.015	.001	.005	0	.003	.003	.002	.005	.0005	.08	.01	.005	0	.1
Do	5.5	.02	.06	.05	.001	.015	.01	.01	.003	.005	.02	.005	.02	.002	.005	0	.01	.005	.005	.007	.001	.1	.02	.01	.02	.1
Socorro: Carthage	14.6	.004	.02	.8	.003	.03	.01	.003	.005	.01	.01	.05	.08	.002	.01	0	.02	.002	.01	.02	.001	.3	.02	.01	0	.1
North Dakota:																										
Bowman: Unknown	16.9	0	.08	.05	.0002	.01	.002	.002	.002	.001	.01	.008	.02	.002	.005	0	.002	.001	0	.003	.001	.1	.002	.005	.03	.08
Burke:																										
Unknown	14.4	0	.01	.08	.0005	.01	.005	.001	.005	.0005	.01	.01	.03	.004	.005	0	.002	.005	.005	.01	.001	.1	.02	.008	.02	.08
Do	12.6	0	.01	.09	.0001	.005	.001	.001	.005	.0005	.01	.01	.05	.005	0	.01	.001	.001	.005	.005	.001	.09	.005	.005	.01	.09
Mercer:																										
Zap	12.1	0	.01	.5	.0001	.005	.005	.001	.001	.001	0	.01	.01	.001	0	0	.001	.001	.01	.005	.0005	.5	.01	.005	.01	.05
Unknown	9.3	0	.01	.5	.0001	.005	.005	.001	.001	.0005	0	.01	.01	.01	0	.01	.001	.001	0	.005	.005	.5	.005	.005	.01	.05
Do	10.6	0	.05	.5	.0002	.004	.005	.002	.001	.0005	.01	.005	.04	.001	.002	0	.002	.002	.002	.004	.0005	.3	.02	.01	.02	.1
Ward:																										
Coteau	7.5	0	.05	.1	.0002	.004	.002	.001	.001	.0005	.008	.003	.03	.001	.002	0	.001	.002	0	.002	.0005	.3	.008	.005	.05	.05
Do	12.4	0	.05	.3	.0001	.003	.002	.002	.001	.0005	0	.02	.05	.002	0	.01	.002	.005	.02	.002	.0008	.2	.005	.005	.05	.03
Ohio:																										
Athens: Middle Kittanning (No. 6)	14.6	.007	.05	.05	.0005	.01	.015	.01	.003	.002	.02	.05	.02	.002	.005	0	.01	.0015	.01	.005	.0007	.05	.02	.005	.003	.1
Belmont:																										
Pittsburgh (No. 8)	10.8	.005	.02	.03	.0005	.005	.02	.002	.005	.005	.01	.02	.02	.002	.005	0	.01	.003	.01	.005	.002	.05	.01	.005	.01	.05
Do	15.4	0	.05	.02	.0005	.01	.02	.005	.002	.001	.01	.03	.01	.001	.005	0	.01	.001	.005	.005	.0005	.05	.01	.003	.005	.08
Do	12.9	.01	.05	.1	.0008	.01	.03	.01	.005	.008	.01	.02	.01	.002	.005	0	.02	.003	.01	.005	.002	.02	.02	.01	.02	.02
Do	9.0	.005	.1	.03	.001	.01	.05	.005	.005	.01	.01	.1	.05	.005	.005	0	.02	.005	.005	.005	.001	.1	.02	.01	.01	.1
Do	11.1	0	.05	.02	.0005	.005	.05	.005	.005	.005	.01	.03	.02	.003	.005	0	.02	.003	.003	.008	.001	.05	.03	.01	.02	.08
Do	10.6	.01	.1	.02	.0005	.008	.03	.002	.008	.001	.01	.05	.03	.003	0	0	.01	.005	.01	.005	.002	.08	.03	.005	.02	.05
Sewickley (No. 9)	11.8	0	.02	.02	.0003	.005	.01	.002	.005	.0008	.01	.1	.01	.002	0	0	.01	.003	.008	.005	.001	.05	.01	.005	.01	.05
Do	11.3	0	.1	.03	.0005	.008	.02	.01	.005	.001	.01	.05	.02	.002	.005	0	.015	.005	.008	.005	.0015	.1	.01	.005	.01	.08
Do	11.6	0	.05	.02	.0005	.01	.02	.005	.003	.0005	.01	.05	.008	.001	.005	0	.02	.002	.01	.005	.0005	.02	.01	.005	.01	.08
Do	12.3	0	.05	.05	.0005	.005	.02	.005	.005	.0008	.01	.05	.01	.002	.005	0	.01	.002	.005	.005	.002	.08	.05	.01	.008	.05
Do	12.4	.008	.08	.08	.0005	.01	.03	.005	.008	.002	.01	.1	.01	.003	.005	0	.02	.005	.01	.008	.002	.1	.02	.01	.02	.1
Carroll:																										
Lower Freeport (No. 7)	12.0	.01	.05	.05	.001	.01	.02	.01	.005	.003	.01	.08	.008	.003	.005	0	.02	.005	.005	.005	.0005	.05	.02	.02	.01	.08
No. 7A	10.2	.03	.05	.05	.001	.01	.02	.008	.005	.005	.01	.08	.02	.01	.005	0	.02	.01	.005	.005	.001	.1	.02	.01	.03	.05
Columbiana:																										
Middle Kittanning (No. 6)	9.6	.08	.02	.02	.001	.01	.02	.01	.005	.01	.01	.05	.02	.02	0	0	.02	.005	.005	.005	.0008	.03	.05	.02	.08	.1
Do	9.1	.05	.02	.03	.0008	.015	.05	.02	.008	.02	.01	.05	.1	.02	.005	0	.02	.01	.005	.01	.0015	.05	.05	.02	.05	.1
Do	9.4	.05	.02	.02	.001	.008	.05	.01	.008	.005	.01	.05	.008	.01	.005	0	.02	.01	.005	.008	.001	.03	.02	.01	.02	.1
Coshocton:																										
Lower Kittanning (No. 5)	7.7	0	.1	.1	.002	.01	.02	.01	.005	.008	.01	.02	.02	.01	0	0	.02	.001	.005	.007	.001	.05	.02	.02	.02	.1
Middle Kittanning (No. 6)	4.5	.01	.15	.05	.001	.008	.02	.005	.005	.005	.01	.08	.02	.01	0	0	.015	.001	.005	.005	.0008	.05	.02	.03	.02	.08
Do	5.9	0	.1	.1	.002	.01	.02	.005	.005	.01	.01	.02	.02	.005	.005	0	.02	.002	.005	.005	.0005	.02	.01	.02	.02	.1
Do	7.8	0	.08	.08	.0002	.003	.02	.005	.003	.0007	.01	.08	.05	.005	.005	0	.01	.001	.01	.005	.0005	.05	.02	.01	.005	.08
Do	12.6	0	.07	.1	.0007	.01	.02	.005	.005	.003	.01	.03	.007	.005	.002	0	.01	.003	.03	.005	.0015	.05	.02	.02	.03	.07
Do	12.7	0	.03	.1	.001	.015	.005	.01	.003	.007	.01	.05	.02	.007	.005	0	.01	.003	.05	.007	.0007	.03	.02	.03	.03	.15
Gallia:																										
Lower Kittanning (No. 5)	17.1	.01	.05	.005	.001	.04	.02	.02	.003	.0005	.02	.01	.01	.002	.005	0	.02	.002	.01	.003	.0005	.1	.03	.02	.02	.1
Pittsburgh (No. 8)	12.6	.03	.05	.03	.0005	.005	.03	.005	.005	.003	.01	.02	.02	.01	0	0	.02	.005	.005	.003	.005	.02	.05	.01	.02	.05
Redstone (No. 8A)	12.0	.01	.05	.05	.001	.01	.03	.005	.008	.005	.02	.02	.05	.005	0	0	.01	.005	.005	.005	.002	.05	.02	.02	.01	.1
Guernsey:																										
Anderson (No. 7A)	11.7	.01	.05	.01	.0008	.01	.03	.01	.005	.015	.02	.05	.1	.02	.005	0	.02	.005	.005	.008	.002	.1	.02	.01	.02	.1
Pittsburgh (No. 8)	11.3	.005	.05	.01	.0005	.005	.05	.005	.005	.008	.01	.01	.02	.003	.005	0	.01	.005	.005	.005	.002	.02	.02	.01	.02	.1
Harrison:																										
Middle Kittanning (No. 6)	11.1	.005	.03	.02	.0008	.008	.02	.01	.003	.002	.01	.02	.02	.005	.005	0	.02	.005	.005	.005	.0005	.02	.02	.01	.02	.08
Pittsburgh (No. 8)	12.6	.01	.03	.02	.0005	.005	.01	.003	.002	.001	.01	.03	.01	.001	.005	0	.01	.001	.005	.005	.0003	.02	.02	.003	.005	.05
Do	12.0	.01	.1	.02	.0005	.01	.03	.005	.003	.002	.01	.03	.01	.005	.005	0	.02	.005	.005	.005	.0008	.05	.02	.01	.01	.08
Do	12.0	.01	.05	.02	.0008	.01	.02	.005	.002	.0008	.01	.05	.01	.003	.005	0	.02	.001	.005	.005	.0002	.02	.02	.005	.01	.08
Sewickley (No. 9)	12.7	0	.05	.05	.0005	.005	.01	.002	.002	.001	.01	.2	.01	.001	.005	0	.01	.001	.005	.008	.0005	.05	.02	.008	.01	.05
Do	13.7	.01	.05	.05	.001	.01	.05	.005	.005	.002	.01	.05	.01	.001	.005	0	.01	.005	.005	.008	.0015	.02	.02	.01	.01	.1
Jackson: Brookville (No. 4)	10.0	.005	.05	.01	.001	.01	.01	.01	.005	.01	.01	.002	.005	.003	.005	0	.01	.002	.01	.005	.001	.05	.02	.02	.03	.1

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, percent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Ohio--Con.																										
Jefferson:																										
Harlem	11.2	0.02	0.03	0.05	0.001	0.02	0.02	0.008	0.005	0.01	0.01	0.05	0.01	0.002	0	0	0.02	0.008	0.01	0.005	0.0008	0.05	0.02	0.02	0.1	0.1
Lower Freeport (No. 6A)	10.4	0	.05	.02	.0005	.008	.01	.02	.001	.0003	.02	.05	.008	.005	.005	0	.02	.0008	.005	.005	0	.08	.05	.02	.02	.07
Lower Kittanning (No. 5)	15.1	.01	.015	.03	.0005	.01	.02	.01	.002	.002	.02	.05	.01	.003	.005	0	.01	.005	.008	.008	.0005	.05	.01	.01	.02	.08
Middle Kittanning (No. 6)	8.6	.02	.02	.05	.001	.01	.02	.01	.005	.008	.02	.05	.008	.005	.005	0	.02	.008	.003	.008	.0005	.05	.02	.02	.05	.08
Pittsburgh (No. 8)	11.5	.01	.05	.02	.0005	.005	.01	.005	.002	.0015	.01	.02	.008	.001	.005	0	.01	.002	.005	.005	.0005	.02	.02	.005	.01	.05
Do	10.4	.01	.02	.05	.0007	.005	.01	.003	.002	.002	.01	.05	.01	.002	.005	0	.015	.001	.005	.005	.0002	.01	.02	.005	.005	.05
Do	9.7	.005	.1	.05	.0003	.008	.02	.01	.005	.008	.01	.03	.02	.002	.005	0	.02	.003	.005	.005	.001	.1	.02	.01	.02	.05
Do	6.8	.005	.1	.01	.001	.01	.03	.003	.005	.001	.01	.01	.01	.005	.005	0	.02	.005	0	.005	.002	.05	.02	.02	.01	.1
Do	12.6	0	.01	.05	.0002	.008	.02	.005	.001	.0005	0	.05	.008	.001	.005	0	.01	.001	.005	.005	.0003	.02	.02	.008	.01	.05
Do	11.5	0	.05	.02	.0005	.005	.01	.005	.002	.003	.01	.05	.01	.001	.005	0	.01	.001	.008	.005	.0005	.02	.05	.003	.015	.05
Do	9.7	.02	.05	.02	.0008	.01	.02	.01	.005	.01	.02	.05	.01	.005	.005	0	.02	.005	.005	.005	.005	.08	.05	.01	.02	.08
Do	15.0	.005	.05	.01	.0002	.008	.01	.005	.003	.0008	.01	.02	.01	.001	.005	0	.01	.001	.005	.005	.0003	.01	.01	.005	.005	.05
Do	11.9	.02	.05	.02	.0005	.005	.02	.005	.005	.001	.01	.02	.008	.002	.005	0	.01	.002	.005	.005	.0005	.02	.02	.005	.01	.08
Lawrence:																										
Lower Kittanning (No. 5)	4.6	.03	.1	.03	.002	.02	.02	.02	.01	.03	0	.1	.01	.03	0	.02	.02	.008	.005	.01	.0008	.08	.03	.02	.05	.05
Wileus	15.5	.01	.05	.05	.0005	.01	.02	.01	.002	.01	.01	.01	.05	.01	.005	0	.01	.002	.02	.003	.001	.1	.02	.005	.05	.08
Mahoning:																										
Brookville (No. 4)	8.8	0	.05	.02	.001	.01	.02	.01	.005	.003	0	.01	.007	.002	.005	0	.01	.002	.02	.005	.0005	.02	.01	.002	.01	.06
Do	7.8	.08	.1	.02	.002	.02	.02	.02	.01	.02	.01	.02	.01	.01	.005	0	.05	.01	.005	.01	.001	.1	.02	.02	.1	.1
Do	14.7	.02	.05	.02	.0005	.01	.03	.008	.005	.005	.01	.02	.02	.01	.005	0	.05	.01	.005	.008	.001	.03	.03	.02	.05	.08
Do	15.1	.01	.005	.02	.0008	.005	.02	.005	.005	.0005	.01	.02	.01	.008	0	0	.01	.003	.008	.003	.001	.02	.01	.01	.01	.05
Do	5.0	.05	.1	.2	.002	.01	.02	.01	.01	.01	.01	.02	.01	.01	.002	0	.03	.01	.005	.008	.005	.15	.05	.05	.05	.08
Meigs:																										
Redstone (No. 8A)	8.7	.01	.05	.03	.001	.01	.03	.01	.008	.002	.02	.08	.01	.005	.005	0	.01	.005	.003	.005	.005	.05	.02	.02	.01	.1
Do	8.5	.03	.05	.03	.0005	.02	.03	.01	.005	.02	.02	.02	.02	.01	.005	0	.02	.01	.005	.005	.005	.08	.03	.02	.02	.1
Morgan:																										
Sewickley (No. 9)	16.7	.01	.05	.1	.0005	.01	.02	.007	.002	.005	.02	.02	.02	.002	.008	0	.01	.002	.02	.008	.0008	.05	.03	.01	.02	.08
Do	14.9	0	.05	.02	.0005	.008	.02	.005	.004	.003	.01	.02	.01	.003	.005	0	.005	.002	.01	.003	.001	.08	.02	.008	.02	.1
Muskingum:																										
Middle Kittanning (No. 6)	11.6	.01	.05	.1	.001	.005	.05	.02	.01	.01	.02	.02	.1	.015	0	0	.01	.005	.02	.008	.001	.02	.05	.05	.01	.08
Do	24.2	0	.03	.01	.0007	.015	.02	.01	.001	.005	.01	.07	.01	.005	.005	0	.01	.0015	.01	.007	.0005	.02	.02	.005	.02	.1
Do	18.1	.01	.05	.1	.001	.005	.02*	.008	.005	.005	.01	.05	.02	.003	.003	0	.01	.005	.01	.005	.0015	.1	.02	.008	.02	.2
Upper Freeport (No. 7)	15.4	0	.05	.1	.001	.01	.02	.005	.003	.005	.01	.02	.02	.005	0	0	.01	.0005	.02	.003	.0005	.05	.01	.005	.02	.05
Noble:																										
Sewickley (No. 9)	18.8	0	.05	.05	.0005	.01	.02	.007	.002	.005	.02	.05	.02	.003	.008	0	.02	.002	.01	.008	.0015	.02	.03	.015	.03	.1
Do	17.2	.01	.03	.1	.0002	.01	.02	.005	.002	.002	.02	.02	.01	.003	.008	0	.01	.002	.02	.01	.0005	.02	.01	.01	.005	.08
Perry:																										
Lower Kittanning (No. 5)	9.5	.005	.08	.05	.0015	.07	.015	.005	.005	.005	.02	.02	.03	.005	.002	0	.05	.005	.008	.007	.0007	.05	.02	.03	.02	.1
Do	12.9	.02	.08	.02	.007	.2	.02	.003	.005	.015	.03	.02	.007	.007	.002	0	.2	.02	.008	.007	.001	.1	.03	.07	.1	.1
Middle Kittanning (No. 6)	12.3	0	.1	.05	.0004	.01	.05	.02	.01	.002	.01	.01	.05	.005	0	0	.02	.005	.03	.005	.001	.05	.05	.05	.05	.1
Do	6.5	.01	.1	.05	.0015	.02	.03	.003	.007	.005	.01	.02	.006	.002	.005	0	.02	.007	.008	.005	.002	.05	.02	.03	.01	.1
Do	10.6	.01	.1	.08	.001	.01	.05	.02	.01	.008	.01	.01	.1	.005	0	0	.02	.01	.01	.008	.001	.05	.05	.03	.02	.08
Do	8.7	0	.05	.05	.0001	.01	.01	.005	.01	.01	0	.05	.01	.005	0	0	.01	.001	.01	.005	.0005	.09	.01	.005	.005	.05
Portage: Brookville (No. 4)	11.3	.015	.08	.02	.001	.1	.02	.008	.008	.01	.03	.08	.01	.005	.002	0	.03	.005	.005	.008	.005	.2	.02	.03	.3	.08
Stark:																										
Middle Kittanning (No. 6)	14.9	.01	.02	.03	.0008	.005	.01	.002	.005	.003	.01	.02	.01	.005	0	0	.02	.003	.008	.005	.001	.02	.02	.005	.05	.05
Do	22.6	.005	.03	.02	.0005	.01	.02	.005	.005	.005	.01	.05	.01	.008	.005	0	.02	.01	.01	.005	.001	.1	.02	.01	.05	.05
Tuscarawas:																										
Lower Kittanning (No. 5)	10.8	.005	.05	.1	.002	.05	.02	.01	.008	.01	.01	.02	.05	.01	.005	0	.05	.005	.005	.008	.001	.02	.02	.02	.05	.08
Do	9.3	.005	.08	.05	.001	.01	.02	.02	.008	.01	.01	.02	.03	.01	.005	0	.05	.008	.01	.005	.001	.05	.05	.02	.03	.08
Do	19.6	.01	.05	.02	.001	.02	.02	.008	.005	.008	.01	.02	.05	.005	.005	0	.05	.01	.01	.005	.001	.02	.02	.02	.1	.02
Middle Kittanning (No. 6)	10.1	.01	.08	.02	.0008	.005	.01	.008	.005	.01	.01	.02	.02	.005	.005	0	.02	.002	.008	.005	.001	.08	.02	.02	.05	.05
Do	8.0	.01	.1	.03	.002	.005	.02	.005	.005	.01	.01	.02	.02	.008	0	0	.02	.005	.005	.005	.002	.02	.02	.01	.02	.05

Vinton: Middle Kittanning (No. 6)	7.8	.005	.1	.02	.0005	.02	.05	.01	.01	.007	.01	.02	.01	.003	.002	0	.02	.003	.001	.007	.0007	.07	.02	.02	.01	.2
Washington: Sewickley (No. 9)	12.2	0	.07	.1	.0005	.01	.03	.007	.002	.005	.02	.02	.01	.005	.008	0	.015	.002	.01	.008	.0008	.02	.02	.01	.03	.08
Pennsylvania:																										
Allegheny:																										
Pittsburgh	9.3	.01	.05	.2	.001	.02	.02	.004	.004	.01	.01	.004	.03	.002	.01	0	.02	.004	.05	.01	.001	.2	.05	.01	.02	.1
Do.	9.5	.02	.03	.2	.0005	.02	.02	.004	.002	.003	.02	.004	.01	.004	.01	0	.01	.002	.02	.01	.0005	.2	.04	.01	.02	.1
Do.	7.9	.02	.02	.005	.0008	.003	.01	.004	.004	.001	.01	.005	.01	.003	.002	0	.005	.01	.01	.005	.002	.1	.02	.01	.02	.08
Do.	26.1	.008	.01	.05	.0005	.01	.015	.007	.003	.002	.015	.008	.04	.002	.005	0	.02	.002	.05	.008	.0008	.09	.05	.007	.02	.1
Do.	9.9	.005	.02	.05	.001	.015	.01	.005	.005	.003	.02	.008	.008	.001	.005	0	.015	.003	.02	.01	.001	.02	.05	.01	.01	.08
Upper Freeport	7.6	.02	.03	.02	.0005	.01	.02	.008	.005	.005	.02	.05	.01	.005	.005	0	.015	.005	.005	.008	.001	.1	.02	.01	.02	.01
Do.	15.3	.02	.01	.02	.0005	.01	.01	.008	.004	.005	.01	.005	.01	.002	.008	0	.01	.008	.02	.005	.0008	.1	.05	.008	.04	.1
Armstrong:																										
Lower Freeport	10.3	.02	.015	.05	.0005	.02	.03	.01	.005	.005	0	.05	.02	.015	0	0	.03	.005	.008	.01	.0008	.1	.02	.015	.015	.05
Lower Kittanning	10.1	0	.01	.02	.0005	.008	.02	.01	.008	.005	0	.15	.015	.01	0	.01	.015	.0008	.02	.005	.0005	.1	.02	.01	.02	.03
Do.	8.7	0	.015	.02	.001	.01	.05	.015	.008	.005	.01	.15	.02	.015	0	.02	.015	.002	.01	.015	.002	.1	.03	.01	.015	.05
Upper Freeport	10.9	.005	.01	.05	.0001	.015	.02	.008	.005	.001	0	.1	.01	.01	0	.02	.01	.001	.05	.005	.0005	.1	.02	.01	.01	.05
Do.	11.1	.005	.01	.1	.0001	.01	.02	.01	.005	.002	.01	.15	.01	.01	0	0	.015	.0008	.05	.005	.0008	.1	.03	.01	.01	.02
Do.	8.7	.08	.02	.08	.0005	.02	.02	.01	.005	.008	.01	.15	.02	.02	0	0	.015	.008	.05	.008	.0008	.1	.02	.01	.02	.03
Do.	10.0	.01	.02	.03	.0005	.01	.05	.01	.005	.002	.01	.1	.01	.005	.005	0	.02	.005	.005	.008	.005	.1	.05	.01	.02	.08
Do.	19.4	.02	.01	.05	.0002	.01	.02	.02	.005	.005	.01	.15	.02	.015	0	0	.02	.005	.1	.01	.0005	.15	.03	.01	.02	.03
Do.	10.5	.005	.01	.05	.0001	.01	.02	.02	.01	.003	.01	.05	.02	.01	0	0	.02	.005	.03	.01	.0005	.1	.03	.01	.01	.03
Beaver:																										
Lower Kittanning	5.9	.02	.03	.07	.001	.01	.01	.015	.01	.001	.01	.005	.005	.003	.005	0	.02	.01	.01	.008	.001	.08	.03	.02	.02	.07
Do.	6.7	.015	.05	.1	.002	.03	.02	.02	.005	.02	.02	.03	.003	.008	.005	0	.05	.006	.01	.01	.0002	.15	.05	.03	.03	.08
Upper Freeport	7.8	.02	.015	.03	.001	.015	.015	.015	.005	.01	.01	.003	.005	.005	.005	0	.015	.01	.002	.005	.001	.05	.02	.01	.01	.07
Bedford: Lower Kittanning	10.2	0	.002	.04	.001	.02	.05	.01	.008	.002	.01	.1	.05	.003	.004	0	.02	.004	.01	.003	.0005	.04	.05	.02	.005	.08
Butler:																										
Brookville	8.9	0	.05	.05	.0005	.015	.01	.005	.004	.001	.015	.01	.008	.002	.005	0	.005	.003	.001	.005	.0015	.02	.01	.01	.01	.1
Do.	8.3	.02	.05	.03	.001	.05	.03	.01	.003	.008	.01	.005	.1	.003	.01	0	.02	.005	.005	.008	.0005	.03	.02	.01	.08	.1
Middle Kittanning	13.4	.05	.01	.02	.001	.01	.02	.005	.002	.005	0	.002	.008	.008	.005	0	.01	.01	0	.005	.001	.01	.01	.005	.05	.1
Upper Freeport	12.4	.05	.01	.08	.001	.02	.02	.05	.005	.005	.02	.01	.005	.01	.005	0	.02	.005	.01	.01	.001	.05	.05	.03	.05	.1
Cambria:																										
Lower Freeport	9.6	.03	.008	.05	.001	.02	.03	.015	.008	.01	.01	.15	.01	.015	0	0	.05	.008	.008	.01	.0008	.02	.03	.015	.05	.05
Lower Kittanning	9.5	.02	.005	.05	.001	.02	.02	.01	.01	.008	.01	.2	.01	.015	.005	.05	.02	.008	.01	.015	.002	.1	.05	.01	.02	.1
Do.	6.5	0	.01	.02	.0005	.01	.02	.01	.005	.0005	.01	.1	.005	.003	.005	0	.01	.005	.005	.008	.0005	.1	.05	.008	.03	.05
Do.	7.7	0	.005	.05	.0001	.01	.02	.01	.01	.002	.01	.1	.03	.015	0	.02	.015	.01	.02	.005	.005	.1	.02	.005	.01	.1
Do.	7.8	.005	.01	.01	.001	.005	.02	.01	.01	.005	0	.02	.02	.01	0	.01	.02	.005	.02	.005	.001	.1	.03	.005	.02	.05
Do.	7.5	.01	.005	.05	.0001	.01	.01	.01	.01	.01	.01	.09	.01	.005	0	.01	.01	.01	.01	.005	.001	.09	.01	.01	.01	.09
Do.	7.3	.005	.005	.02	.0001	.008	.02	.01	.01	.001	.01	.08	.01	.002	0	.02	.01	.005	.02	.005	.0008	.1	.02	.01	.01	.03
Do.	8.4	.03	.01	.05	.0001	.02	.03	.01	.01	.003	.01	.1	.01	.015	.005	.05	.03	.008	.02	.015	.001	.08	.03	.015	.02	.1
Do.	7.9	.005	.008	.02	.0008	.03	.05	.015	.01	.005	.015	.1	.02	.02	0	.05	.02	.01	.01	.015	.002	.05	.05	.008	.08	.1
Do.	9.3	.01	.008	.08	.0005	.015	.03	.01	.01	.003	.01	.2	.01	.015	0	.05	.02	.008	.05	.015	.001	.1	.03	.02	.01	.1
Do.	7.5	.005	.01	.05	.0008	.015	.03	.015	.008	.0015	0	.15	.01	.015	0	.05	.02	.005	.02	.002	.0008	.1	.03	.015	.02	.15
Do.	8.7	.02	.007	.05	.001	.02	.05	.01	.005	.007	.01	.03	.05	.002	.003	0	.02	.007	.02	.007	.001	.05	.02	.02	.03	.15
Do.	10.9	0	.003	.05	.0001	.015	.02	.01	.005	.001	.01	.1	.005	.005	0	.03	.015	.001	.01	.01	.0005	.1	.05	.015	.005	.1
Upper Freeport	8.2	.02	.003	.1	0	.02	.02	.005	.005	.01	.01	.08	.01	.015	0	.02	.01	.008	.1	.01	.0005	.1	.01	.01	.015	.08
Do.	8.3	0	.01	.05	.001	.01	.03	.01	.01	.01	.01	.02	.01	.01	.005	.02	.01	.008	.1	.01	.002	.03	.02	.02	.08	.05
Do.	12.4	.01	.003	.02	.0001	.01	.02	.008	.005	.0005	.01	.1	.005	.005	0	0	.02	.005	.01	.01	.0005	.02	.02	.008	.005	.03
Do.	12.0	.02	.01	.1	.001	.01	.05	.01	.005	.002	.01	.1	.02	.015	0	0	.015	.005	.05	.008	.0008	.1	.02	.01	.01	.03
Do.	13.2	.01	.005	.09	.0001	.02	.02	.008	.005	.0015	.01	.05	.02	.015	0	.02	.015	.005	.09	.008	.0003	.09	.02	.008	.01	.05
Upper Kittanning	9.3	.03	.008	.05	.001	.015	.02	.02	.01	.005	.01	.05	.02	.01	.003	.01	.05	.01	.02	.01	.0005	.05	.02	.01	.08	.05
Do.	10.7	0	.008	.05	.0005	.02	.02	.02	.008	.005	.01	.15	.015	.015	0	0	.03	.008	.03	.02	.0008	.05	.03	.01	.05	.02
Do.	8.3	0	.005	.09	.0008	.05	.02	.05	.005	.002	.01	.09	.02	.02	0	.05	.03	.008	.09	.015	.0005	.09	.01	.01	.015	.05
Do.	10.3	.01	.008	.1	.0001	.02	.03	.02	.01	.008	.01	.15	.02	.02	0	.03	.03	.008	.05	.01	.001	.1	.03	.01	.05	.05
Clarion:																										
Clarion	9.9	.01	.05	.02	.0008	.01	.05	.01	.03	.003	.01	.02	.03	.01	.005	0	.02	.005	.005	.005	.001	.1	.05	.02	.01	.1
Middle Kittanning	7.2	0	.015	.02	.0005	.015	.01	.01	.01	.01	0	.1	.01	.01	0	.02	.02	.002	.005	.005	.0005	.08	.02	.01	.01	.02
Clearfield:																										
Lower Freeport	13.2	.01	.01	.05	.001	.05	.05	.02	.03	.005	.02	,1	.02	.01	0	0	.02	.01	.005	.01	.001	.1	.05	.02	.08	.08
Do.	9.2	.05	.005	.1	.0008	.01	.02	.008	.005	.008	.01	.08	.01	.015	0	.01	.02	.001	.01	.005	.0005	.1	.02	.01	.01	.08
Do.	9.9	0	.003	.08	.0001	.01	.01	.002	.002	.008	0	.03	.015	.02	0	.02	.015	.001	.1	.008	.0005	.08	.02	.005	.008	.015
Do.	8.5	.01	.003	.05	.0001	.015	.015	.008	.002	.003	0	.08	.015	.015	0	.02	.01	.001	.05	.005	.0005	.08	.02	.005	.008	.02
Lower Kittanning	12.6	0	.003	.1	.0001	.008	.01	.008	.002	.001	0	.05	.01	.005	0	0	.005	.0008	.05	.003	.0003	.1	.02	.005	.005	.03
Do.	10.9	.003	.005	.03	.0005	.01	.02	.005	.005	.001	0	.1	.02	.01	0	.01	.01	.001	.01	.005	.0005	.08	.02	.01	.01	.08
Do.	9.5	.01	.005	.1	.0008	.02	.02	.01	.01	.01	.01	.02	.01	.015	0	.02	.02	.008	.02	.01	.002	.15	.02	.015	.02	.05

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, percent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Pennsylvania--Con.																										
Clearfield--Con.																										
Middle Kittanning	11.0	0.01	0.003	0.05	0.0001	0.01	0.01	0.01	0.002	0.0015	0	0.03	0.01	0.01	0	0	0.01	0.0008	0.02	0.01	0.0005	0.08	0.03	0.008	0	0.05
Upper Freeport	11.5	.01	.005	.15	.0015	.02	.01	.01	.008	.01	.01	.005	.03	.005	.005	0	.02	.005	.1	.01	.001	.1	.05	.02	.03	.09
Do	11.4	.08	.01	.3	.001	.03	.05	.01	.005	.01	.01	.1	.015	.02	0	.02	.03	.008	.05	.005	.0005	.1	.03	.015	.02	.1
Do	15.2	.08	.008	.2	.0008	.05	.05	.02	.01	.01	.01	.05	.1	.03	0	.05	.02	.015	.08	.01	.0008	.05	.02	.015	.03	.1
Do	12.5	.08	.01	.08	.001	.03	.05	.01	.01	.01	.01	.02	.02	.03	0	.03	.03	.01	.05	.01	.001	.05	.03	.02	.1	.1
Upper Kittanning	11.9	.01	.005	.02	.001	.02	.02	.05	.01	.003	.01	.1	.01	.005	.005	0	.01	.01	.005	.008	.001	.05	.05	.01	.02	.08
Elk: Clarion	9.7	.015	.01	.5	.002	.015	.02	.015	.005	.005	.01	.005	.005	.005	.005	0	.015	.002	.002	.007	.0005	.05	.03	.02	.01	.08
Fayette:																										
Pittsburgh	9.5	.007	.05	.05	.001	.02	.03	.005	.003	.002	0	.05	.04	.004	.005	0	.02	.005	.02	.003	.001	.1	.02	.02	.02	.1
Do	9.2	.015	.02	.05	.0005	.01	.02	.005	.003	.007	.01	.08	.02	.002	.005	0	.015	.002	.01	.008	.0015	.1	.02	.008	.01	.07
Redstone (bottom bench)	10.8	.02	.05	.05	.002	.01	.05	.01	.01	.01	.02	.02	.1	.015	.005	0	.03	.01	.01	.02	.005	.05	.05	.01	.02	.05
Redstone (top bench)	10.4	.008	.05	.05	.001	.01	.05	.01	.02	.005	.02	.05	.1	.01	.005	0	.05	.01	.002	.02	.005	.02	.03	.02	.02	.05
Greene:																										
Pittsburgh	11.2	.004	.05	.1	.0005	.01	.02	.003	.004	.002	.02	.05	.02	.003	.01	0	.01	.005	.02	.01	.001	.3	.05	.005	0	.1
Do	9.1	.02	.03	.05	.0002	.01	.02	.02	.01	.005	.01	.05	.05	.01	0	.02	.01	.01	.01	.005	.005	.05	.03	.005	.005	.05
Sewickley	13.0	.01	.01	.02	.0005	.01	.01	.005	.002	.0005	.01	.02	.02	.002	.005	0	.01	.002	.02	.005	.001	.1	.02	.005	.02	.08
Huntingdon: Clarion	7.4	.02	.008	.02	.001	.004	.05	.01	.02	.005	.01	.04	.01	.01	.004	0	.01	.005	.01	.003	.002	.04	.05	.01	.01	.04
Indiana:																										
Lower Freeport	9.4	.015	.005	.1	.001	.015	.02	.01	.005	.005	.01	.1	.05	.015	0	.02	.02	.001	.02	.01	.0005	.1	.02	.008	.015	.05
Do	11.3	.02	.01	.08	.001	.015	.02	.02	.005	.01	.015	.1	.008	.02	0	.02	.015	.005	.01	.01	.0005	.1	.03	.015	.01	.03
Do	8.7	.01	.01	.02	.001	.05	.05	.02	.008	.01	.02	.1	.01	.01	.005	0	.05	.005	.005	.01	.001	.05	.08	.01	.03	.08
Do	11.3	.01	.005	.15	.0001	.02	.03	.02	.005	.005	.01	.1	.015	.02	0	0	.02	.001	.02	.01	.0008	.05	.03	.015	.03	.05
Lower Kittanning	8.0	0	.008	.02	.0001	.015	.02	.015	.01	.008	.01	.15	.015	.015	0	.01	.01	.005	.01	.02	.0008	.15	.08	.01	.008	.03
Do	8.6	0	.01	.02	.001	.015	.03	.015	.01	.005	.01	.1	.01	.015	.005	.02	.02	.005	.008	.02	.0005	.2	.08	.01	.01	.05
Do	10.9	0	.005	.05	.0001	.015	.02	.01	.01	.005	.01	.05	.02	.015	0	0	.02	.02	.05	.008	.0005	.1	.02	.01	.01	.05
Do	8.9	.005	.005	.08	.0001	.02	.02	.02	.005	.002	.01	.2	.01	.015	.005	.02	.02	.002	.05	.01	.001	.15	.05	.02	.02	.03
Do	9.8	0	.002	.2	.0001	.008	.01	.005	.01	.0005	0	.1	.005	.001	0	0	.005	.001	.02	.002	.0002	.1	.01	.003	.005	.02
Upper Freeport	10.2	.08	.01	.05	.0005	.02	.05	.01	.01	.001	.01	.1	.03	.02	0	.03	.02	.005	.1	.01	.0008	.15	.02	.01	.015	.08
Do	8.8	.015	.005	.05	.001	.01	.02	.01	.005	.02	.01	.05	.005	.005	.005	0	.01	.005	.005	.005	.0005	.05	.05	.005	.03	.05
Do	10.9	.08	.002	.05	.0001	.02	.02	.005	.005	.008	.01	.1	.01	.03	0	.02	.015	.008	.15	.01	.0005	.1	.01	.01	.05	.05
Do	8.2	.01	.005	.02	.0005	.02	.01	.01	.005	.002	.01	.008	.005	.002	.005	0	.01	.003	.01	.005	.0005	.1	.01	.01	.005	.1
Do	7.2	0	.005	.05	.0001	.01	.001	.003	.002	.002	.01	.08	.01	.001	.002	0	.01	.0005	.05	.008	.0003	.1	.03	.008	.01	.02
Do	10.1	.008	.01	.05	.0001	.01	.02	.008	.002	.0005	.01	.1	.02	.015	0	.02	.01	.0008	.1	.01	.0005	.2	.02	.01	.008	.02
Jefferson: Lower Kittanning	7.6	.01	.01	.1	.002	.03	.05	.05	.02	.005	.03	.02	.01	.01	.01	0	.02	.005	.003	.015	.002	.2	.05	.03	.02	.1
Lawrence:																										
Brookville	10.1	.02	.03	.07	.002	.015	.01	.01	.005	.01	.02	.03	.005	.005	.005	0	.02	.008	.02	.008	.0005	.15	.04	.02	.01	.1
Do	10.3	.02	.03	.07	.002	.02	.02	.01	.01	.001	.01	.05	.001	.002	.005	0	.02	.01	.008	.008	.0005	.07	.03	.02	.02	.08
Lower Kittanning	5.4	.02	.08	.04	.003	.03	.02	.01	.01	.001	.02	.008	.002	.01	.005	0	.1	.02	.001	.009	.0005	.1	.02	.02	.05	.08
Do	11.2	.05	.03	.1	.002	.015	.01	.02	.01	.01	.01	.005	.01	.005	.005	0	.02	.01	.005	.005	.001	.05	.02	.02	.02	.08
Luzerne: Unknown	12.8	0	.003	.04	.0005	.02	.04	.015	.005	.0015	.02	.01	.05	.002	.005	0	.015	.005	.005	.008	.001	.03	.08	.02	.01	.09
Mercer:																										
Brookville	5.7	.005	.05	.02	.0005	.01	.01	.003	.005	.001	.01	.01	.05	.002	.005	0	.01	.003	.001	.005	.001	.02	.015	.01	.02	.05
Do	8.4	0	.05	.02	.0008	.008	.01	.002	.005	.001	.01	.015	.05	.001	.003	0	.01	.005	.008	.003	.003	.15	.01	.01	.05	.08
Northumberland:																										
Unknown	13.8	0	.005	.02	.0005	.01	.01	.002	.002	.0005	.02	.02	.005	.001	.005	0	.01	.0007	.003	.005	.0007	.01	.05	.005	.005	.1
Do	11.1	.005	.004	.08	.001	.02	.01	.02	.005	.002	.02	.01	.02	.002	.008	0	.01	.008	.004	.007	.001	.07	.02	.02	.05	.09
Schuylkill:																										
Mammoth and Buck Mountain	10.6	.005	.005	.1	.0005	.02	.02	.03	.005	.0008	.02	.05	.01	.002	.005	0	.02	.003	.01	.008	.001	.1	.02	.01	.01	.1
Unknown	11.0	0	.007	.1	.0005	.05	.02	.01	.01	.003	.02	.01	.009	.005	.01	0	.02	[illegible]	.02	.01	.001	.15	.09	.015	.04	.1
Do	13.7	0	.003	.05	.0005	.02	.01	.015	.002	.0005	.02	.1	.05	.001	.01	0	.01	[illegible]	.01	.01	.001	.05	.03	.01	.02	.1
Somerset:																										
Lower Kittanning	8.0	.02	.01	.15	.0005	.015	.02	.015	.005	.0008	.02	.02	.008	.003	.008	0	.02	.005	.005	.008	.001	.05	.05	.02	.005	.08
Do	6.7	.005	.01	.08	.001	.05	.03	.015	.005	.001	.02	.01	.005	.002	.01	0	.02	.002	.02	.01	.001	.2	.05	.01	.02	.1
Washington:																										
Pittsburgh	8.0	.02	.05	.02	.0005	.01	.05	.005	.002	.005	.01	.1	.02	.01	.002	0	.02	.0008	.005	.005	.0003	.1	.03	.01	.02	.1
Do	9.8	0	.02	.05	.0008	.01	.02	.008	.005	.002	.01	.05	.02	.008	0	0	.015	.001	.005	.01	.001	.2	.05	.01	.008	.05

Westmoreland:																									
Pittsburgh	8.1	0	.02	.05	.0003	.02	.02	.01	.005	0	.008	.1	.02	.01	.002	.02	.02	.003	.05	.01	.0008	.1	.03	.01	.01	.08
Upper Freeport	11.9	.01	.008	.2	.0005	.01	.01	.008	.005	.002	0	.08	.01	.01	0	.015	.015	.0008	.05	.005	.003	.15	.02	.005	.01	.08
Do	7.6	0	.01	.05	.0001	.01	.01	.008	.005	.001	0	.02	.02	.01	0	.01	.01	.0008	.05	.005	.0005	.1	.02	.008	.01	.08
Do	8.2	.01	.01	.05	.001	.01	.02	.008	.008	.005	0	.05	.02	.01	0	0	.01	.005	.02	.005	.001	.15	.02	.01	.01	.02
Do	12.1	.02	.05	.02	.005	.02	.05	.01	.01	.005	.01	.05	.02	.02	.005	0	.02	.01	.005	.005	.005	.02	.05	.02	.02	.1
Tennessee:																									
Anderson:																									
Dean	16.5	.005	.02	.2	.0002	.008	.02	.005	.002	.0002	.01	.2	.01	.015	0	0	.01	.0008	.1	.01	.0005	.1	.02	.005	.02	.03
Pee Wee	7.7	0	.02	.1	.0005	.015	.015	.02	.002	.003	.015	.1	.01	.015	0	.02	.02	.0008	.1	.03	.0005	.2	.05	.01	.015	.015
Campbell:																									
Dean	13.9	0	.01	.08	.0002	.005	.015	.01	.01	.0005	.01	.05	.01	.01	.002	.01	.005	.008	.01	.005	.001	.1	.02	.005	.005	.05
Jellico	13.5	0	.02	.08	.0002	.015	.02	.01	.01	.001	.01	.1	.03	.005	.002	.02	.015	.008	.05	.01	.0008	.1	.05	.01	.05	.05
Do	2.8	.02	.05	.1	.001	.015	.03	.03	.005	.003	.02	.03	.1	.005	.005	0	.015	.003	0	.007	.002	.15	.05	.05	.02	.1
Pee Wee	10.0	0	.02	.1	.0005	.02	.02	.01	.005	.001	.01	.05	.02	.01	.002	.02	.02	.005	.05	.01	.0008	.05	.03	.01	.01	.02
Do	6.8	0	.03	.08	.001	.02	.02	.01	.008	.005	.01	.02	.02	.01	.002	.03	.02	.01	.02	.008	.005	.1	.05	.01	.01	.03
Claiborne:																									
Jellico	4.8	.02	.05	.15	.001	.02	.02	.02	.01	.01	.02	.05	.02	.01	.005	.03	.02	.01	.015	.02	.002	.1	.03	.01	.08	.05
Do	5.2	.01	.03	.15	.001	.02	.02	.01	.002	.002	.015	.01	.05	.01	0	.02	.02	.0008	.1	.01	.0005	.2	.03	.015	.02	.05
Mason	6.2	0	.02	.05	.0005	.01	.02	.02	.01	.005	.01	.05	.02	.01	.005	.02	.02	.01	.1	.01	.01	.02	.05	.01	.05	.05
Do	10.7	.02	.015	.1	.001	.02	.02	.02	.005	.0015	.02	.1	.05	.003	.005	0	.02	.005	.05	.005	.0005	.05	.02	.008	.03	.05
Sterling	8.2	.01	.02	.1	.0001	.008	.01	.008	.005	.001	.01	.1	.015	.005	0	0	.01	.005	.005	.003	.001	.15	.01	.01	.01	.03
Do	12.5	0	.008	.1	.0001	.005	.01	.008	.002	.001	.02	.2	.01	.001	.005	0	.01	.0008	.01	.015	.0008	.1	.02	.01	.005	.03
Grundy:																									
Sewanee	9.6	.005	.015	.1	.0008	.015	.015	.01	.002	.008	.01	.1	.02	.002	0	.03	.015	.008	.2	.01	.0005	.1	.03	.01	.02	.02
Do	9.9	0	.015	.1	.001	.015	.01	.01	.005	.008	.015	.2	.01	.002	0	.03	.015	.008	.2	.015	.0008	.1	.05	.01	.02	.015
Upper Sewanee	9.7	.02	.01	.1	.0005	.01	.01	.01	.008	.002	.02	.015	.008	.001	.005	0	.01	.002	.08	.007	.001	.1	.02	.01	.015	.07
Marion: Sewanee	10.0	0	.01	.22	.0005	.01	.01	.005	.002	.002	.01	.02	.02	.001	0	.01	.01	.0008	.03	.005	.0008	.2	.02	.008	.02	.02
Morgan: Glen Mary	6.1	.03	.03	.1	.0008	.015	.03	.01	.008	.0008	.01	.1	.01	.015	0	0	.02	.0008	.02	.008	.0008	.2	.03	.001	.02	.02
Putnam: Bon Air No. 2	13.1	.005	.03	.08	.0005	.01	.015	.005	.002	.001	.005	.1	.02	.008	0	.01	.01	.01	.1	.005	.008	.3	.015	.005	.01	.05
Scott:																									
Glen Mary	5.6	.003	.02	.4	.0005	.02	.02	.008	.003	.008	.015	.2	.005	.01	0	.03	.03	.0008	.05	.03	.0008	.1	.08	.008	.02	.03
Do	9.6	.03	.02	.08	.0008	.015	.05	.005	.01	.01	.01	.05	.02	.015	0	0	.015	.0008	.008	.005	.0008	.2	.02	.008	.005	.2
Unknown	17.2	0	.02	.05	.0002	.02	.02	.01	.005	.0008	.01	.2	.03	.01	.002	.01	.01	.005	.08	.005	.0008	.3	.03	.01	.01	.05
Sequatchie: Sewanee	11.8	.005	.015	.1	.0003	.01	.01	.008	.002	.0015	.015	.1	.02	.002	0	.01	.015	.0008	.08	.01	.0008	.2	.03	.008	.02	.02
Utah:																									
Carbon:																									
Castlegate D	8.1	0	.05	.12	.0002	.003	.005	.002	.001	0	0	.003	.007	.001	.005	0	.001	.001	0	.002	.001	.1	.005	.003	.01	.08
Do	9.6	0	.04	.12	.0002	.005	.005	.002	.002	.0005	0	.003	.005	.001	.005	0	.002	.001	.008	.002	.001	.1	.01	.003	.005	.07
Do	6.6	0	.02	.2	.0001	.005	.005	.001	.002	.0005	0	.005	.005	.001	0	.01	.002	.001	0	.002	.001	.15	.01	.002	.005	.05
Castlegate Sub I	6.4	0	.1	.2	.0005	.008	.01	.005	.005	.002	0	.015	.01	.001	0	.015	.008	.002	.005	.003	.005	.15	.015	.01	.005	.03
Unknown	6.2	0	.08	.03	.0005	.008	.005	.002	.002	.0005	.01	.005	.005	.001	.005	0	.005	.001	.01	.002	.001	.1	.005	.01	.015	.1
Do	6.1	0	.1	.1	.0005	.005	.01	.005	.003	.001	.01	.005	.005	.001	.002	0	.002	.005	.002	.002	.001	.15	.01	.008	.02	.1
Do	5.8	0	.1	.1	.001	.005	.01	.005	.002	.0005	.01	.01	.01	.001	.002	0	.003	.001	.002	.002	.0002	.1	.01	.015	.02	.1
Do	8.0	0	.08	.03	.001	.01	.01	.003	.003	.001	.01	.008	.01	.001	.005	0	.015	.002	0	.005	.0005	.1	.01	.01	.02	.1
Do	5.7	0	.05	.05	.0001	.003	.01	.005	.002	.001	0	.05	.05	.002	0	0	.005	.0008	0	.002	.0008	.3	.01	.002	.005	.02
Do	7.0	.005	.1	.1	.0005	.01	.005	.01	.003	.001	.01	.02	.002	.001	.005	0	.002	.002	.005	.005	.001	.1	.01	.005	.02	.1
Do	6.7	0	.08	.05	.0005	.01	.02	.005	.002	.0005	.02	.005	.01	.002	.005	0	.006	.003	.002	.004	.002	.3	.02	.01	.02	.1
Do	5.9	0	.1	.1	.0002	.005	.01	.01	.002	.0005	.01	.008	.008	.001	.005	0	.008	.002	.005	.005	.001	.1	.02	.005	.01	.1
Emery:																									
Blind Canyon	6.8	0	.08	.08	.0002	.005	.01	.001	.005	.0005	.01	.01	.005	.001	.005	0	.005	.004	0	.005	.001	.1	.01	.01	.01	.1
Ferron "A"	6.3	0	.08	.08	.0002	.005	.005	.002	.002	.0008	.01	.008	.01	.001	.005	0	.008	.003	0	.002	.001	.1	.01	.005	.01	.08
Ferron J	8.2	0	.03	.2	0	.005	.01	.002	.002	.0005	0	.1	.02	.002	0	.01	.005	.005	0	.003	.0008	.2	.01	.005	.01	.05
Hiawatha	7.4	0	.09	.1	.0002	.008	.005	.005	.005	.0005	.01	.05	.008	.001	.005	0	.005	.002	0	.005	.0015	.15	.01	.005	.005	.1
Do	8.0	0	.08	.3	.0002	.008	.01	.003	.005	.0005	.02	.02	.02	.002	.002	0	.005	.005	0	.004	.005	.1	.02	.005	.01	.1
Lower Sunnyside	6.2	0	.1	.3	.0002	.008	.008	.004	.005	.001	.03	.05	.02	.001	.004	0	.003	.005	.005	.005	.002	.2	.02	.01	.01	.1
Do	6.9	0	.3	.1	.0001	.008	.01	.002	.01	.001	.02	.15	.03	.002	.008	.05	.008	.005	0	.008	.001	.2	.015	.01	[illegible]	.1
Unknown	9.6	0	.08	.05	.0002	.01	.01	.005	.002	.0005	.01	.01	.005	.001	.005	0	.005	.001	.01	.005	.0005	.15	.01	.005	.005	.1
Do	7.2	0	.09	.02	.0005	.01	.01	.005	.001	.0005	.01	.01	.005	.001	.005	0	.01	.001	.005	.005	.0005	.1	.01	.005	.01	.1
Sevier: Hiawatha	6.9	0	.1	.1	0	.003	.01	.002	.002	.0005	0	.005	.1	.002	0	.01	.001	.0008	0	.003	.001	.1	.01	.002	.005	.1
Virginia																									
Buchanan:																									
Clintwood	6.2	.02	.01	.1	.003	.02	.02	.02	.015	.01	.015	.1	.03	.02	.005	0	.05	.01	.02	.01	.002	.15	.05	.02	.02	.05
Eagle	9.1	.02	.05	.1	.003	.02	.05	.02	.01	.005	.02	.02	.1	.02	.005	0	.1	.01	.05	.02	.005	.05	.05	.02	.08	.05

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, per-cent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
Virginia--Con.																										
Buchanan--Con.																										
Hagy	6.3	0.005	0.01	0.08	0.001	0.01	0.02	0.02	0.005	0.005	0.01	0.05	0.05	0.01	0.005	0.01	0.02	0.005	0.01	0.005	0.0008	0.05	0.05	0.01	0.02	0.05
Do	5.5	.05	.01	.1	.002	.05	.01	.02	.002	.005	.02	.01	.01	.005	.005	0	.02	.003	.002	.005	.0005	.1	.05	.02	.01	.1
Do	8.0	0	.01	.1	.0005	.01	.02	.01	.005	.001	.01	.15	.1	.001	.005	0	.01	.005	.008	.01	.002	.1	.05	.01	.02	.05
Jewell	2.8	.01	.01	.15	.002	.05	.01	.02	.003	.002	.01	.02	.05	.01	.005	0	.05	.005	.005	.005	.001	.3	.02	.02	.005	.08
Kennedy	4.0	.02	.02	.1	.002	.05	.05	.02	.02	.008	.02	.02	.1	.02	.005	.01	.05	.01	.01	.01	.005	.1	.08	.02	.05	.05
Do	7.7	.015	.02	.1	.0005	.015	.02	.015	.003	.001	.015	.1	.05	.007	.005	0	.02	.005	.02	.003	.0005	.1	.05	.01	.01	.07
Lower Banner	14.3	.015	.01	.1	.0005	.01	.01	.015	.005	.0005	.01	.03	.01	.001	.005	0	.01	.002	.03	.005	.001	.08	.015	.01	.005	.08
[illegible]n	6.0	.05	.01	.1	.002	.02	.05	.02	.02	.008	.01	.02	.1	.02	.003	.01	.05	.01	.02	.01	.01	.05	.1	.02	.01	.03
Do	4.4	.02	.02	.2	.002	.02	.05	.05	.01	.005	.02	.05	.1	.02	.005	.01	.05	.02	.01	.01	.01	.1	.05	.02	.05	.05
Do	2.7	.01	.02	.1	.005	.02	.03	.02	.002	.002	.015	.01	.1	.02	0	.01	.05	.005	0	.005	.005	.1	.03	.02	.005	.05
Do	7.1	.015	.01	.1	.001	.01	.05	.02	.01	.002	.015	.02	.1	.01	.002	.01	.03	.01	.02	.015	.005	.1	.03	.02	.02	.02
Splash Dam	10.6	.005	.02	.2	.0005	.01	.02	.02	.01	.005	.01	.1	.02	.01	.005	.01	.02	.01	.3	.005	.0008	.3	.05	.01	.005	.05
Do	5.7	.005	.02	.1	.001	.02	.02	.005	.003	.001	.02	.05	.007	.003	.005	0	.01	.002	.007	.01	.0005	.07	.02	.015	0	.1
Do	5.3	0	.02	.07	.001	.01	.02	.005	.005	.002	.02	.1	.01	.001	.005	0	.01	.007	.005	.003	.001	.2	.02	.007	.005	.07
Do	6.8	.03	.05	.1	.002	.02	.08	.03	.02	.01	.02	.05	.05	.015	.01	.02	.05	.02	.01	.02	.008	.1	.02	.02	.05	.1
Do	6.9	.01	.02	.1	.001	.02	.05	.02	.01	.008	.02	.05	.05	.01	.005	.02	.05	.008	.01	.015	.002	.1	.1	.02	.02	.05
Do	6.8	0	.01	.15	.0008	.005	.01	.008	.005	.0005	.01	.1	.005	.001	.005	0	.01	.003	.005	.005	.001	.1	.02	.01	.008	.05
Do	6.3	.02	.02	.06	.002	.02	.05	.02	.01	.01	.02	.03	.05	.01	.005	0	.02	.01	.07	.01	.008	.1	.02	.02	.02	.05
Do	5.5	.01	.01	.1	.002	.02	.03	.02	.015	.01	.02	.05	.03	.01	.005	.02	.05	.01	.02	.015	.005	.1	.1	.02	.08	.05
Dickenson:																										
Hagy	8.8	.02	.01	.1	.001	.01	.03	.02	.01	.01	.015	.05	.02	.01	.005	0	.03	.008	.01	.01	.002	.1	.05	.02	.08	.05
Kennedy	2.7	.015	.01	.07	.002	.02	.005	.02	.002	.005	.015	.01	.008	.005	.005	0	.01	.003	.005	.003	.0005	.1	.02	.01	.007	.07
Lower Banner	6.3	.01	.01	.1	.0005	.015	.01	.01	.005	.0005	.02	.01	.1	.003	.005	0	.01	.003	.001	.007	.001	.12	.02	.01	.005	.1
Do	12.1	0	.02	.05	.0003	.01	.02	.02	.01	.0008	.02	.05	.1	.01	.005	0	.01	.008	.02	.01	.005	.1	.02	.01	.005	.05
Upper Banner	10.0	0	.01	.1	.001	.015	.02	.01	.01	.005	.02	.05	.1	.005	.005	0	.02	.01	.01	.01	.002	.1	.05	.02	.05	.02
Do	6.6	.005	.05	.1	.0008	.01	.02	.008	.01	.002	.01	.02	.1	.02	.005	.01	.02	.01	.06	.005	.005	.06	.02	.01	.015	.05
Lee:																										
Taggart	7.9	.005	.02	.3	.002	.02	.02	.02	.01	.002	.02	.02	.1	.01	.005	0	.05	.008	.02	.008	.001	.2	.03	.02	.01	.03
Do	2.8	0	.02	.2	.005	.015	.01	.02	.01	.005	.01	.01	.01	.01	.002	.02	.02	.005	.01	.005	.005	.2	.02	.01	.05	.02
Montgomery:																										
Brushy Mountain	31.7	0	.01	.02	.0002	.01	.02	.005	.008	.001	.01	.1	.03	.001	.005	.02	.01	.02	0	.01	.001	.005	.02	.01	.1	.05
Russell:																										
Jawbone	14.0	0	.002	.1	.0005	.005	.005	.003	.002	.0005	.01	.03	.01	.001	.005	0	.005	.001	.01	.005	.0005	.15	.01	.005	0	.07
Kennedy	12.5	.02	.01	.5	.0005	.01	.02	.015	.01	.008	.01	.05	.08	.02	.005	.02	.02	.01	.03	.005	.005	.2	.03	.01	.01	.05
Do	6.2	.03	.04	.1	.001	.01	.01	.015	.003	.0005	.01	.02	.1	.01	0	0	.01	.005	.015	.005	.0005	.2	.02	.015	.007	.07
Lower Banner	9.9	0	.02	.1	.0005	.01	.02	.01	.01	.002	.01	.02	.1	.01	.005	0	.02	.008	.01	.01	.002	.1	.05	.01	.1	.03
Raven	13.3	.005	.01	.2	.0005	.01	.02	.02	.01	.002	.01	.05	.05	.01	.005	.02	.01	.008	.3	.01	.002	.1	.03	.01	.02	.05
Tiller	12.9	.005	.005	.1	.0005	.02	.02	.015	.005	.001	.02	.01	.05	.002	.008	0	.01	.005	.02	.01	.001	.1	.03	.01	.02	.09
Do	6.2	.005	.005	.08	.001	.01	.01	.01	.005	.0005	.02	.01	.05	.002	.005	0	.01	.003	.02	.005	.001	.15	.02	.01	.005	.1
Do	5.8	0	.003	.1	.001	.01	.01	.005	.002	.0005	.01	.08	.005	.002	.005	0	.01	.001	.005	[illegible]	.001	.1	.03	.02	0	.05
Do	13.1	0	.005	.1	.0005	.01	.02	.01	.005	.0005	.02	.15	.02	.002	.005	0	.01	.003	.005	.01	.001	.15	.05	.01	.005	.08
Tazewell:																										
Raven	7.7	0	.01	.3	.001	.02	.02	.02	.01	.005	.01	.05	.1	.01	.005	.02	.02	.01	.05	.008	.001	.2	.05	.02	.008	.03
Upper Seaboard	6.2	.01	.008	.1	.001	.015	.01	.01	.005	.001	.01	.1	.02	.001	.005	0	.01	.005	.01	.005	.0015	.3	.02	.01	.01	.05
Wise:																										
Blair	5.7	0	.015	.2	.002	.03	.02	.02	.01	.002	.02	.02	.02	.02	.005	.01	.05	.008	.02	.02	.005	.2	.1	.02	.05	.05
Do	7.4	.01	.01	.06	.002	.02	.02	.02	.01	.005	.02	.02	.08	.02	.005	0	.02	.01	.05	.02	.003	.04	.05	.02	.05	.02
Clintwood	6.2	.01	.02	.2	.001	.02	.03	.02	.01	.005	.02	.01	.03	.02	.005	.01	.05	.008	.005	.01	.005	.2	.03	.02	.02	.05
Dorchester	8.3	.01	.01	.06	.0005	.015	.05	.02	.01	.005	.01	.03	.03	.015	.005	0	.02	.01	.03	.01	.008	.1	.05	.01	.015	.05
Imboden	8.3	.02	.015	.03	.001	.015	.03	.02	.01	.005	.02	.03	.05	.02	.005	0	.05	.01	.02	.01	.003	.04	.1	.02	.05	.05
Lyons	5.4	.03	.02	.15	.001	.02	.05	.02	.01	.01	.01	.02	.05	.015	.005	0	.03	.02	.06	.02	.005	.06	.08	.015	.05	.05
Do	5.5	.02	.02	.2	.001	.01	.02	.02	.01	.005	.01	.03	.03	.02	.005	.01	.05	.005	.02	.01	.002	.2	.05	.02	.02	.02
Taggart	4.4	.01	.02	.2	.002	.03	.02	.02	.02	.01	.01	.02	.08	.02	.005	0	.07	.01	.03	.01	.005	.04	.05	.015	.1	.05
Do	1.8	.01	.04	.2	.005	.07	.01	.03	.005	.005	.02	.02	.01	.01	.005	0	.05	.005	.002	.007	.001	.2	.02	.02	.02	.1

Washington:																										
King:																										
Black Knight	9.5	0	.1	.15	.0003	.01	.01	.01	.008	.001	.01	.02	.01	.001	.005	0	.01	.005	.003	.01	.001	.1	.02	.008	.02	.1
Do	22.4	0	.05	.05	.0003	0	.01	.01	.008	.001	0	.02	.005	.001	.005	0	.005	.005	.005	.005	.001	.05	.05	.003	.02	.1
Pierce:																										
Wilkeson	12.4	0	.005	.1	.0005	.02	.02	.01	.005	.001	.02	.004	.005	.003	.01	0	.01	.002	.02	.002	.001	.3	.08	.01	.02	.1
No. 3	11.2	0	.01	.1	.0005	.02	.01	.01	.005	.0007	.01	.05	.03	.002	.01	0	.01	.001	.001	.01	.0005	.5	.03	.01	.05	.2
No. 7	6.1	0	.03	.5	.0002	.05	.015	.02	.005	.001	.02	.03	.02	.005	.02	0	.02	.0015	.01	.02	.0015	.5	.07	.02	.02	.2
No. 8	14.2	0	.01	.15	.0002	.01	.01	.01	.005	.0007	.01	.02	.01	.002	.007	0	.01	.0015	.01	.005	.0007	.2	.02	.005	.01	.1
No. 11	13.0	0	.015	.15	.0005	.02	.01	.015	.005	.001	.01	.05	.005	.005	.01	0	.015	.0015	.01	.01	.0007	.5	.03	.01	.03	.1
West Virginia:																										
Barbour:																										
Lower Kittanning	10.6	.01	.02	.03	.001	.01	.05	.02	.02	.005	.01	.01	.03	.02	.002	0	.03	.01	.005	.01	.0008	.02	.05	.01	.01	.05
Do	12.4	.01	.02	.1	.001	.015	.08	.02	.02	.005	.02	.02	.03	.01	.005	0	.03	.01	.06	.02	.002	.06	.05	.02	.05	.03
Pittsburgh	8.8	0	.03	.1	.0005	.008	.02	.005	.004	.002	.01	.01	.02	.002	.005	0	.01	.002	.008	.004	.0005	.15	.02	.01	.03	.1
Do	9.0	0	.05	.1	.0002	.01	.02	.01	.005	.001	0	.03	.05	.005	0	0	.01	.003	.005	.005	.001	.15	.02	.005	.005	.1
Do	8.8	.01	.05	.1	.0005	.005	.02	.01	.005	.003	.01	.05	.02	.005	0	0	.01	.005	.005	.005	.0005	.15	.01	.01	.01	.08
Do	9.1	0	.07	.1	.0003	.005	.05	.01	.005	.0008	.01	.03	.1	.005	.005	0	.015	.005	.005	.005	.001	.2	.05	.01	.005	.2
Do	9.8	0	.08	.2	.0003	.02	.05	.015	.005	.001	.01	.03	.05	.005	.005	0	.02	.005	.005	.008	.001	.1	.05	.02	.01	.1
Redstone	7.1	.01	.05	.1	.002	.01	.05	.008	.008	.01	.01	.05	.08	.005	.005	0	.01	.005	.005	.01	.002	.2	.02	.01	.01	.1
Do	8.5	.01	.02	.1	.001	.01	.05	.01	.005	.005	.01	.15	.05	.008	.005	0	.02	.005	.005	.008	.001	.2	.05	.02	.01	.1
Upper Freeport	16.2	.02	.01	.03	.0005	.05	.02	.01	.005	.002	0	.02	.02	.01	0	0	.01	.003	.003	.005	.0005	.07	.01	.01	.03	.1
Upper Kittanning	14.2	.01	.02	.05	.0005	.02	.02	.01	.005	.0005	.01	.05	.01	.003	.005	0	.01	.005	.007	.005	.0008	.1	.02	.01	.01	.1
Do	13.3	.02	.02	.05	.001	.02	.05	.02	.02	.002	.02	.05	.05	.01	.005	.01	.02	.01	.02	.01	.002	.1	.03	.01	.01	.08
Boone:																										
Alma	8.5	.02	.02	.05	.001	.01	.02	.02	.005	.001	.01	.01	[illegible]	.001	.003	0	.01	.005	.01	.003	.001	.1	.01	.005	.005	.07
Campbell Creek	11.6	.01	.05	.05	.002	.02	.02	.01	.005	.002	.02	.1	[illegible]	.003	.008	0	.02	.005	.01	.008	.001	.1	.05	.03	.02	.1
Do	5.2	.01	.03	.05	.002	.04	.02	.02	.003	.002	.03	.007	.01	.005	.01	0	.02	.005	.008	.015	.001	.1	.02	.015	0	.1
Cedar Grove	3.3	.01	.1	.1	.002	.05	.05	.05	.01	.005	.02	.05	.02	.015	.005	0	.05	.008	.005	.008	.002	.2	.1	.02	.01	.1
Do	8.6	.008	.03	.05	.001	.02	.03	.02	.01	.002	.02	.08	.01	.003	.005	0	.02	.01	.005	.003	.005	.1	.08	.02	.02	.1
Do	5.2	0	.01	.05	.001	.015	.02	.02	.005	.001	.02	.01	.02	.001	.01	0	.01	.003	.001	.01	.002	.1	.02	.02	.02	.1
Do	6.1	.01	.02	.1	.001	.02	.02	.015	.005	.002	.02	.01	.02	.005	.01	0	.015	.005	.02	.01	.002	.15	.03	.02	.05	.08
Do	6.3	.02	.05	.05	.001	.02	.02	.01	.01	.01	.01	.15	.008	.001	.005	0	.02	.01	.008	.008	.005	.15	.03	.01	.01	.07
Chilton	6.0	0	.05	.15	.001	.05	.03	.02	.01	.003	.01	.2	.008	.002	.005	0	.02	.01	.008	.01	.003	.15	.02	.02	.02	.1
Coalburg	14.3	0	.01	.1	.0005	.01	.02	.02	.008	.001	.02	.2	.005	.002	.005	0	.015	.005	.008	.01	.002	.2	.05	.01	.01	.08
Hernshaw	4.5	0	.01	.05	.005	.015	.01	.005	.008	.005	.01	.05	.002	.001	.005	0	.02	.003	0	.005	.001	.1	.02	.01	.005	.05
Lower Kittanning	27.9	0	.005	.05	.0002	.005	.01	.005	.005	.005	.01	.1	.008	.001	.005	0	.01	.002	.008	.005	.0005	.02	.02	.003	.005	.08
Stockton-Lewiston	10.7	0	.01	.02	.0008	.01	.01	.01	.005	.001	.01	.1	.001	.003	.005	0	.02	.002	.005	.005	.001	.05	.05	.01	.01	.05
Do	11.0	0	.01	.05	.002	.01	.01	.01	.005	.001	.01	.1	.003	.001	.005	0	.02	.005	.002	.005	.001	.01	.03	.005	.005	.08
Winifrede	13.0	0	.02	.08	.0005	.01	.02	.02	.005	.002	.01	.15	.01	.001	.005	0	.02	.005	.02	.01	.002	.1	.05	.01	.02	.05
Do	8.2	0	.02	.05	.0005	.01	.008	.01	.002	.0005	.01	.05	.005	.001	.005	0	.02	.001	.003	.005	.001	.05	.02	.005	.005	.07
Do	8.5	0	.01	.1	.02	.01	.01	.01	.005	.002	.01	.02	.01	0	.005	0	.01	.003	.003	.005	.0008	.07	.01	.01	0	.08
Do	14.7	.01	.01	.1	.0005	.01	.02	.01	.005	.001	.01	.1	.008	.001	.005	0	.02	.005	.01	.008	.001	.2	.03	.005	.01	.05
Braxton:																										
Pittsburgh	5.9	.01	.03	.3	.0008	.015	.015	.005	.002	.0005	0	.08	.03	.015	0	.01	.01	.0005	.1	.002	.0003	.2	.02	.008	.01	.08
Do	6.0	.01	.05	.1	.001	.03	.05	.01	.005	.01	.01	.05	.1	.01	.005	0	.02	.005	.007	.005	.001	.15	.02	.01	.02	.1
Do	7.6	.02	.015	.1	.0003	.01	.015	.003	.002	.005	0	.05	.02	.02	0	.01	.015	.0005	.08	.008	.0008	.1	.02	.003	.01	.03
Upper Kittanning	4.8	0	.02	.1	.0015	.02	.015	.015	.01	.003	.015	.1	.02	.015	0	.01	.02	.008	.05	.015	.0008	.3	.1	.015	.015	.05
Clay:																										
Lower Kittanning	12.1	0	.01	.1	.0001	.02	.03	.005	.01	.001	.01	.2	.005	.015	.005	0	.02	.002	.02	.015	.0005	.05	.03	.01	.005	.03
Do	10.8	0	.01	.15	.001	.015	.02	.01	.008	.001	.01	.05	.02	.005	0	.03	.015	.001	.01	.01	.0005	.1	.03	.01	.005	.08
Do	7.1	0	.02	.08	.0008	.008	.02	.01	.01	.0015	.01	.1	.015	.002	0	.03	.015	.008	.03	.01	.001	.1	.03	.01	.01	.015
Fayette:																										
Campbell Creek	6.3	0	.01	.2	.0005	.02	.02	.02	.01	.002	.01	.1	.05	.003	0	.02	.02	.008	.05	.015	.001	.2	.03	.01	.015	.03
Coalburg	7.5	0	.02	.08	0	.02	.02	.01	.01	.001	.01	.1	.02	.01	0	0	.02	.005	.008	.015	.001	.1	.05	.008	.01	.03
Fire Creek	5.3	.015	.015	.1	.002	.05	.02	.02	.002	.002	.03	.05	.007	.01	.01	0	.02	.002	.007	.01	.0015	.05	.05	.02	.01	.1
Do	6.4	.005	.01	.2	.001	.05	.02	.02	.003	.005	.02	.01	.02	.007	.005	0	.03	.001	.02	.01	.0005	.1	.05	.02	.02	.1
Lower Eagle	6.0	.03	.02	.1	.002	.03	.03	.02	.02	.02	.02	.05	.02	.01	.01	.005	.02	.008	.02	.02	.002	.1	.1	.02	.015	.02
Lower Kittanning	5.9	0	.015	.08	.001	.02	.02	.02	.01	.0008	.01	.1	.05	.015	0	.02	.01	.008	.005	.01	.001	.15	.02	.01	.015	.03
Gilmer:																										
Pittsburgh	11.6	.008	.02	.1	.0002	.015	.02	.003	.005	.002	.01	.1	.02	.02	0	0	.015	.0008	.01	.01	.0005	.1	.03	.008	.008	.2
Do	9.7	.02	.03	.1	.0001	.01	.02	.005	.01	.005	.01	.02	.1	.02	.002	.01	.02	.01	.01	.008	.002	.1	.05	.01	.01	.05
Do	5.6	.01	.05	.1	.001	.03	.01	.007	.005	.01	.015	.007	.05	.01	.007	0	.02	.002	.05	.005	.001	.1	.03	.01	.02	.1
Do	7.7	.01	.05	.1	.0002	.005	.02	.01	.008	.001	.01	.05	.05	.01	.002	.01	.01	.005	.01	.005	.008	.1	.02	.01	.01	.05
Greenbrier:																										
Beckley	5.6	.05	.01	.1	.002	.05	.01	.02	.005	.005	.03	.008	.01	.01	.005	0	.03	.005	.05	.01	.001	.15	.02	.02	.07	.1
Sewell	4.6	.02	.02	.1	.001	.05	.05	.02	.005	.01	.02	.005	.05	.01	.005	0	.05	.005	.02	.015	.001	.1	.05	.02	.05	.1

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, percent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
West Virginia--Con.																										
Harrison:																										
Pittsburgh	9.9	0.015	0.03	0.1	0.001	0.05	0.03	0.001	0.005	0.015	0.01	0.015	0.02	0.007	0.005	0	0.02	0.005	0.02	0.007	0.003	0.1	0.05	0.02	0.03	0.15
Do	9.2	0	.05	.08	.0002	.008	.01	.003	.003	.001	0	.02	.01	.002	0	0	.005	.002	.01	.005	.0008	.15	.015	.003	.005	.05
Do	8.0	0	.05	.2	.0002	.01	.02	.003	.005	.001	.01	.02	.02	.002	.005	0	.01	.002	.005	.005	.0008	.2	.05	.005	.005	.1
Do	6.3	.005	.1	.1	.0002	.005	.03	.005	.005	.005	.01	.05	.02	.005	.005	0	.01	.005	.005	.005	.001	.2	.02	.008	.01	.1
Do	8.2	0	.1	.1	.0005	.008	.05	.008	.005	.003	.01	.02	.02	.008	.002	0	.02	.005	.005	.005	.001	.1	.05	.01	0	.08
Do	10.2	0	.02	.05	.0002	.005	.01	.002	.003	.003	.01	.02	.008	.002	0	0	.01	.007	.002	.003	.0008	.03	.008	.005	.005	.05
Do	13.1	.01	.02	.1	.0005	.01	.02	.005	.003	.008	.01	.02	.008	.005	.005	0	.01	.001	.005	.005	.0005	.05	.02	.01	.005	.1
Do	9.7	.005	.05	.08	.0005	.01	.01	.005	.002	.001	.01	.005	.01	.005	.005	0	.01	.001	.02	.005	.0005	.1	.015	.01	.008	.08
Do	7.8	0	.05	.1	.0005	.01	.02	.002	.005	.005	.01	.02	.01	.002	.005	0	.02	.002	.005	.005	.001	.05	.02	.005	.003	.1
Redstone	8.9	.008	.03	.2	.0005	0	.01	.005	.005	.001	.01	.02	.01	.003	.005	0	.01	.002	.008	.005	.0005	.1	.01	.003	.005	.05
Do	7.8	.01	.1	.1	.0005	.005	.02	.005	.005	.002	.01	.01	.02	.002	.005	0	.01	.005	.005	.005	.002	.15	.02	.005	.005	.05
Do	7.4	0	.02	.08	.0003	.005	.01	.005	.002	.0008	.02	.02	.01	.002	.005	0	.01	.001	.005	.008	.0005	.2	.02	.005	.008	.05
Do	8.0	0	.05	.1	.0005	.005	.02	.005	.005	.008	.01	.02	.01	.002	.005	0	.01	.005	.005	.005	.0008	.1	.05	.005	.005	.08
Do	5.9	.01	.02	.2	.0005	.005	.01	.01	.003	.0005	0	.01	.01	.001	.005	0	.005	.002	.005	.005	.001	.05	.01	.005	.005	.05
Kanawha:																										
Campbell Creek	4.5	0	.03	.2	.002	.01	.003	.01	.01	.005	.005	.02	.003	.002	.002	0	.005	.008	.01	.002	.002	.2	.005	.008	.005	.01
Do	6.2	.03	.02	.15	.002	.02	.02	.02	.01	.002	.01	.15	.1	.02	0	.02	.05	.008	.05	.008	.01	.2	.05	.015	.005	.05
Do	7.2	.01	.01	.1	.001	.003	.02	.02	.005	.002	.01	.1	.01	.001	.005	0	.01	.005	.003	.005	.001	.15	.02	.01	.01	.08
Do	7.5	.008	.01	.2	.001	.005	.01	.01	.008	.001	.01	.2	.008	.002	.005	0	.01	.005	.008	.008	.001	.15	.02	.008	.005	.08
Do	4.5	0	.02	.05	.005	.02	.01	.02	.005	.005	.02	.1	.05	.003	.005	0	.05	.005	.002	.01	.0005	.1	.1	.03	.01	.05
Do	3.2	.05	.1	.06	.002	.02	.05	.05	.02	.01	.05	.02	.05	.05	.005	.02	.1	.02	.006	.02	.005	.06	.1	.05	.02	.08
Do	9.4	.008	.02	.06	.002	.01	.05	.02	.02	.01	.01	.03	.02	.01	.005	0	.05	.01	.02	.02	.002	.1	.05	.02	.005	.05
Do	9.3	.01	.01	.05	.001	.01	.01	.01	.005	.002	.01	.05	.05	.001	.005	0	.02	.002	.005	.005	.001	.05	.02	.01	.01	.08
Do	6.4	.2	.02	.1	.001	.02	.02	.01	.008	.005	.02	.1	.008	.003	.01	0	.015	.005	.005	.02	.001	.1	.02	.02	.01	.02
Cedar Grove	5.3	0	.03	.2	.005	.03	.02	.02	.01	.01	.03	.05	.05	.005	.005	0	.03	.005	.005	.02	.0008	.1	.08	.05	.02	.1
Do	4.8	.01	.02	.3	.002	.015	.015	.015	.01	.0015	.015	.2	.01	.015	0	.01	.02	.008	.1	.01	.008	.2	.03	.015	.02	.05
Do	4.5	.01	.02	.05	.002	.02	.02	.03	.005	.01	.01	.02	.01	.003	.005	0	.03	.005	.003	.01	.0005	.1	.05	.02	.005	.1
Coalburg	12.2	0	.01	.05	.0005	.01	.01	.01	.005	.0015	.02	.08	.005	.001	.005	0	.01	.005	.005	.006	.0005	.05	.02	.01	.005	.05
Do	11.9	0	.005	.05	.002	.01	.01	.005	.005	.001	.01	.05	.003	0	.005	0	.001	.002	.01	.005	.0005	.05	.05	.005	.005	.1
Eagle	4.9	0	.02	.05	.0015	.01	.01	.01	.005	.0008	.02	.05	.005	.002	.005	0	.01	.003	.002	.01	.0005	.15	.02	.02	.005	.06
Eagle A	3.6	0	.01	.05	.03	.1	.05	.05	.02	.02	.01	.05	.1	.001	.005	0	.1	.007	.003	.008	.001	.1	.05	.05	.005	.1
Lower Kittanning	4.1	.008	.02	.05	.0008	.02	.01	.02	.005	.003	.02	.05	.005	.003	.005	0	.03	.005	.003	.008	.0008	.05	.03	.02	.005	.1
Do	4.7	.005	.02	.1	.0005	.02	.008	.005	.005	.0005	.01	.05	.01	.002	.005	0	.02	.005	.01	.005	.003	.2	.02	.01	.02	.05
Do	12.0	0	.01	.05	.002	.01	.02	.01	.01	.002	.02	.05	.01	.002	.008	0	.03	.008	.02	.01	.001	.05	.05	.02	.005	.05
Do	14.3	0	.02	.1	.002	.03	.02	.01	.005	.001	.02	.1	.02	.001	.005	0	.02	.005	.01	.01	.0007	.07	.03	.01	.02	.1
Do	6.1	.01	.02	.05	.005	.01	.02	.02	.005	.0008	.02	.05	.005	.001	.005	0	.02	.005	0	.01	.001	.05	.02	.02	.01	.02
Do	13.9	.01	.015	.05	.002	.02	.05	.005	.02	.005	.01	.02	.01	.01	.005	.01	.05	.05	.01	.008	.005	.02	.05	.01	.005	.05
Do	15.7	.01	.01	.1	.001	.02	.02	.02	.005	.001	.02	.02	.01	.001	.01	0	.01	.005	.02	.003	.001	.05	.05	.01	.005	.1
Pittsburgh	7.0	.05	.05	.1	.001	.01	.05	.02	.005	.01	.02	.03	.05	.015	.005	0	.02	.01	.005	.005	.002	.1	.02	.02	.02	.2
Do	8.0	.005	.015	.05	.0001	.01	.01	.01	.002	.002	0	.02	.015	.005	0	0	.01	.0005	.03	.002	.0008	.08	.02	.005	.005	.03
Do	6.4	.02	.02	.1	.0005	.01	.02	.005	.003	.0003	.01	.02	.05	.003	.005	0	.01	.002	.005	.005	.0005	.05	.02	.005	.01	.1
Powellton	10.9	0	.01	.15	.002	.02	.02	.01	.005	.01	.01	.1	.005	.001	.005	0	.02	.02	.01	.005	.0005	.1	.01	.02	.2	.08
Do	7.2	.005	.005	.09	.0001	.015	.015	.015	.002	.001	.01	.09	.015	.01	0	0	.01	.001	.09	.01	.001	.09	.02	.01	.1	.1
Stockton-Lewiston	6.5	0	.02	.05	.0008	.008	.01	.02	.005	.0008	.02	.05	.003	.001	.005	0	.02	.002	.002	.008	.0015	.2	.05	.01	.02	.08
Do	8.1	0	.02	.05	.0005	.01	.02	.01	.008	.0008	.02	.1	.01	.001	.005	0	.02	.002	.01	.008	.001	.1	.04	.02	.002	.1
Do	6.1	.01	.01	.05	.005	.02	.01	.01	.005	.005	.02	.02	.005	.001	.005	0	.02	.003	.005	.005	.0005	.02	.02	.02	.005	.05
Upper Kittanning	10.0	.005	.05	.02	.0008	.01	.03	.02	.01	.005	.01	.02	.05	.01	.005	.02	.02	.01	.1	.01	.001	.05	.05	.01	.05	.05
Winifrede	3.6	0	.08	.05	.02	.03	.08	.1	.08	.02	.02	.05	.02	.01	.01	.02	.2	.08	0	.02	.01	.1	.1	.08	.01	.05
Do	10.2	0	.01	.1	.0005	.01	.02	.02	.005	.002	.02	.05	.01	.002	.005	0	.01	.005	.005	.01	.0005	.1	.02	.02	.005	.08
Lewis:																										
Pittsburgh	9.4	.015	.03	.1	.0005	.01	.02	.005	.005	.003	0	.008	.02	.003	.005	0	.01	.002	.01	.005	.001	.1	.015	.01	.03	.1
Do	8.6	0	.02	.1	.0005	.01	.02	.002	.008	.01	0	.02	.02	.01	0	.01	.01	.005	.01	.01	.0005	.15	.01	.01	.01	.05
Do	9.2	.05	.1	.1	.0005	.007	.05	.01	.02	.01	.01	.02	.1	.02	.005	0	.02	.02	.005	.01	.005	.1	.02	.01	.005	.1
Redstone	8.6	.02	.1	.1	.0008	.01	.05	.01	.01	.01	.01	.01	.1	.02	0	0	.02	.007	.02	.01	.002	.1	.02	.01	.01	.05
Do	8.4	.03	.05	.1	.0005	.01	.05	.01	.01	.003	.01	.01	.1	.015	0	0	.02	.01	.01	.005	.002	.1	.02	.01	.01	.1

Logan:																										
Campbell Creek...........	7.9	0	.02	.1	.003	.05	.02	.01	.005	.003	.02	.2	.01	.001	.003	0	.02	.003	0	.01	.001	.1	.01	.03	.01	.3
Cedar Grove..............	7.8	0	.005	.05	.0005	.01	.008	.008	.005	.001	.01	.05	.01	.001	.005	0	.01	.0015	.005	.005	.001	.05	.02	.005	.01	.05
Do....................	7.2	.02	.01	.1	.0015	.005	.002	.01	.005	.002	0	.1	.002	0	0	0	.005	.002	.007	.003	.001	.1	.005	.003	.02	.02
Do....................	6.1	.01	.02	.1	.002	.015	.02	.02	.01	.01	.01	.05	.02	.005	.005	.01	.02	.008	.01	.02	.005	.2	.05	.02	.01	.05
Do....................	5.9	.005	.01	.07	.001	.02	.01	.01	.005	.002	.02	.005	.008	.001	.005	0	.02	.003	.01	.01	.001	.1	.03	.02	.01	.1
Do....................	8.6	.05	.02	.05	.001	.01	.02	.01	.015	.01	.015	.02	.03	.01	.02	.005	.02	.01	.01	.01	.001	.1	.05	.02	.005	.05
Do....................	9.4	.015	.02	.05	.002	.02	.03	.02	.01	.005	.02	.01	.02	.01	.01	.005	.03	.01	.01	.015	.002	.08	.02	.02	.08	.05
Chilton..................	5.6	0	.02	.05	.001	.02	.02	.02	.02	.008	.03	.02	.03	.01	.03	.002	.05	.01	.002	.02	.005	.1	.1	.05	.02	.05
Do....................	13.9	0	.01	.1	.001	.015	.005	.005	.005	.0015	.02	.03	.01	.001	.007	0	.01	.005	0	.005	.0015	.05	.015	.05	.005	.2
Do....................	2.9	.015	.02	.005	.005	.02	.02	.015	.007	.007	.01	.04	.01	.001	.002	0	.05	.003	.007	.015	.0005	.2	.05	.05	.01	.2
Do....................	5.2	0	.02	.05	.003	.02	.01	.02	.008	.005	.03	.05	.005	.001	.005	0	.02	.005	0	.008	.0015	.15	.02	.05	.05	.1
Do....................	5.0	0	.01	.05	.008	.03	.01	.02	.01	.01	.02	.03	.005	.001	.005	0	.02	.005	0	.008	.001	.1	.02	.05	.02	.1
Eagle....................	4.1	0	.03	.1	.002	.03	.02	.01	.008	.005	.02	.1	.005	.001	.005	0	.02	.005	.005	.008	.001	.2	.02	.02	.08	.08
Hernshaw.................	4.2	0	.008	.1	.0015	.015	.01	.01	.005	.002	.01	.1	.02	.002	0	.02	.015	.0008	.01	.01	.0005	.2	.03	.01	.005	.08
Lower Cedar Grove........	5.1	.005	.01	.1	.005	.05	.02	.02	.01	.005	.03	.007	.01	.002	.01	0	.02	.01	.02	.01	.002	.15	.05	.02	.08	.1
Lower Kittanning.........	9.5	0	.01	.08	.0001	.01	.01	.01	.005	.001	.01	.08	.005	.005	0	0	.015	.005	.005	.015	.0008	.05	.03	.01	.01	.02
Marion:																										
Pittsburgh...............	7.7	.005	.05	.1	.0005	.015	.01	.005	.005	.003	.01	.01	.01	.002	.005	0	.01	.005	.01	.005	.001	.1	.02	.01	.01	.07
Do....................	7.5	.005	.05	.08	.0002	.005	.005	.002	.001	.0005	.01	.005	.008	.001	.005	0	.008	.002	.01	.003	.0005	.1	.01	.002	.005	.06
Do....................	10.0	.01	.05	.07	.0005	.008	.01	.003	.003	.001	0	.005	.02	.002	.005	0	.01	.005	.005	.005	.001	.05	.01	.005	.01	.07
Do....................	7.5	0	.02	.1	.0001	.01	.02	.008	.002	.005	.01	.15	.01	.01	0	0	.01	.0008	.02	.01	.0008	.1	.02	.005	.01	.02
Do....................	5.8	0	.05	.1	.0002	.01	.01	.001	.002	.01	.01	.03	.005	.003	.005	0	.01	.01	.02	.005	.008	.15	.03	.005	.01	.08
Do....................	10.6	0	.02	.05	.0002	.008	.005	.002	.002	.002	.01	.005	.008	.001	.005	0	.002	.002	.005	.002	.001	.1	.002	.002	.005	.03
Sewickley................	11.7	0	.03	.08	.0005	.01	.02	.005	.005	.001	.01	.005	.05	.001	.005	0	.01	.002	.02	.008	.002	.1	.03	.005	.01	.1
Mason:																										
Pittsburgh...............	14.9	.01	.03	.1	.001	.01	.02	.008	.005	.008	.01	.2	.08	.005	0	.02	.01	.008	.03	.01	.0005	.1	.03	.015	.01	.02
Do....................	17.0	.01	.02	.1	.001	.015	.02	.008	.005	.008	.015	.2	.02	.008	0	.03	.01	.008	.01	.01	.0005	.1	.03	.01	.015	.03
McDowell:																										
Douglas..................	4.0	.02	.005	.1	.005	.05	.02	.02	.008	.02	.02	.005	.01	.003	.005	0	.02	.005	.1	.01	.003	.15	.03	.015	.06	.1
Pocahontas No. 3.........	6.7	0	.01	.08	.001	.02	.05	.03	.01	.002	.01	.2	.1	.01	0	0	.02	.008	.02	.01	.0008	.2	.03	.01	.02	.03
Mercer: Pocahontas No. 3..	6.5	0	.005	.1	.001	.02	.01	.02	.005	.0015	.02	.1	.01	.003	.005	0	.02	.005	.015	.008	.0008	.1	.03	.02	.01	.07
Mingo:																										
Alma.....................	10.9	.007	.01	.1	.001	.03	.015	.01	.001	.002	.02	.1	.02	.001	.005	0	.01	.001	.04	.005	.001	.2	.02	.005	.02	.1
Do....................	3.9	.005	.03	.07	.001	.04	.01	.02	.008	.002	.01	.01	.008	.002	.005	0	.02	.005	.01	.008	.001	.15	.03	.02	.005	.01
Do....................	3.3	.01	.07	.1	.002	.02	.01	.02	.001	.005	.02	.05	.01	.001	.01	0	.02	.01	.001	.01	.001	.2	.02	.02	.05	.1
Campbell Creek...........	5.7	.01	.01	.1	.0005	.02	.005	.01	.002	.0005	.01	.08	.01	.002	.005	0	.02	.0005	.008	.008	.0005	.15	.02	.02	.005	.08
Cedar Grove..............	3.4	.005	.03	.1	.001	.02	.01	.015	.003	.0005	.02	.005	.005	.001	.008	0	.02	.005	.001	.008	.001	.05	.02	.02	.005	.1
Eagle....................	4.3	.03	.01	.1	.001	.02	.01	.02	.005	.001	.01	.02	.005	.005	.005	0	.02	.002	.01	.01	.002	.15	.03	.01	.03	.07
Lower Cedar Grove........	5.1	.008	.05	.1	.001	.05	.02	.03	.005	.005	.02	.05	.005	.002	.01	0	.02	.005	.01	.015	.001	.2	.05	.02	.02	.1
Do....................	5.3	.01	.02	.15	.0015	.05	.02	.005	.005	.005	.03	.1	.007	.005	.01	0	.02	.005	.01	.015	.001	.2	.03	.03	.03	.1
Monongalia:																										
Pittsburgh...............	9.0	0	.05	.05	.0005	.005	.01	.002	.004	.001	.01	.007	.02	.002	.005	0	.005	.008	.005	.002	.002	.3	.01	.008	.005	.08
Do....................	9.0	.006	.05	.1	.001	.01	.02	.005	.005	.005	0	.05	.01	.002	.005	0	.01	.02	.005	.002	.001	.1	.02	.05	.02	.1
Do....................	9.2	.005	.03	.1	.0002	.01	.01	.003	.002	.0005	.01	.005	.005	.002	.003	0	.005	.002	.02	.002	.0005	.1	.01	.005	.01	.08
Do....................	7.7	0	.02	.08	.0005	.005	.02	.002	.005	.002	.01	.01	.01	.002	.005	0	.02	.01	.005	.01	.001	.1	.02	.01	0	.09
Redstone.................	11.0	0	.01	.08	.0005	.02	.02	.01	.003	.002	.02	.008	.01	.002	.005	0	.015	.002	.02	.01	.001	.1	.02	.01	.02	.08
Do....................	11.9	.01	.005	.02	.001	.01	.02	.009	.005	.004	.01	.02	.02	.002	.005	0	.015	.0015	.005	.01	.002	.1	.02	.008	.03	.1
Sewickley................	12.0	0	.03	.1	.0003	.015	.03	.008	.01	.002	.015	.08	.02	.015	0	.02	.01	.001	.03	.01	.0008	.1	.03	.01	.02	.08
Do....................	10.1	0	.03	.2	.0005	.005	.03	.004	.003	.005	.01	.008	.02	.002	.002	0	.02	.01	.008	.005	.001	.1	.02	.005	.02	.05
Do....................	11.5	0	.02	.05	.001	.01	.02	.02	.005	.005	.01	.05	.01	.005	.005	0	.015	.005	.01	.008	.001	.1	.015	.02	.01	.1
Upper Freeport...........	14.3	0	.008	.03	.0005	.01	.01	.002	.004	.001	.01	.006	.004	.001	.005	0	.01	.002	.02	.005	.0005	.1	.02	.003	.02	.07
Do....................	14.3	.01	.01	.05	.0002	.008	.01	.005	.002	.0005	.01	.005	.005	.002	.002	0	.01	.002	.015	.008	.0005	.1	.03	.004	.01	.08
Upper Kittanning.........	9.8	.01	.01	.02	.0005	.02	.007	.005	.005	.002	.01	.008	.001	.002	.005	0	.02	.01	.002	.005	.001	.02	.015	.01	.03	.05
Waynesburg...............	14.5	.005	.03	.08	.0002	.01	.05	.008	.01	.001	.02	.05	.02	.01	.005	.01	.05	.005	.02	.01	.002	.1	.03	.01	.01	.05
Do....................	17.6	0	.02	.1	.001	.01	.02	.005	.01	.005	.01	.05	.01	.005	.002	.01	.01	.005	.05	.01	.0008	.05	.02	.01	.01	.05
Do....................	17.4	0	.01	.07	.0005	.015	.01	.002	.003	.0005	.02	.01	.005	.001	.001	0	.005	.002	.01	.01	.0005	.07	.015	.005	.02	.1
Nicholas:																										
Campbell Creek...........	4.9	.03	.02	.2	.002	.015	.02	.02	.02	.008	.02	.05	.05	.02	.002	.01	.02	.005	.02	.01	.005	.2	.03	.02	.01	.03
Do....................	7.0	0	.01	.1	.0005	.03	.02	.01	.01	.01	.01	.1	.03	.01	.005	.02	.02	.008	.01	.01	.002	.3	.05	.01	.05	.03
Do....................	3.3	.1	.02	.2	.0015	.05	.02	.02	.08	.08	.01	.02	.01	.02	0	0	.05	.008	.01	.01	.001	.3	.08	.02	.02	.02
Coalburg.................	6.8	0	.02	.1	.001	.015	.02	.01	.005	.001	.02	.1	.01	.015	.005	0	.02	.0008	.02	.015	.0005	.15	.08	.01	.005	.05
Eagle....................	7.6	0	.02	.08	.001	.02	.05	.02	.01	.01	.01	.2	.01	.01	.005	0	.02	.008	.05	.02	.005	.2	.03	.008	.02	.03
Do....................	7.8	.005	.01	.07	.0005	.02	.01	.007	.008	.004	.02	.01	.01	.002	.01	0	.02	.002	.02	.015	.001	.1	.03	.009	.02	.08
Do....................	9.5	0	.005	.08	.0001	.015	.001	.008	.005	.005	0	.15	.005	.002	.005	0	.01	.0008	.1	.01	.0008	.1	.03	.008	0	.015
Do....................	7.4	0	.01	.1	.0002	.01	.01	.01	.005	.001	.01	.2	.02	.01	.005	0	.01	.0008	.08	.01	.0005	.2	.05	.01	.005	.02
Do....................	5.2	0	.01	.05	.001	.05	.01	.02	.01	.004	.02	.01	.008	.002	.01	0	.04	.005	.005	.01	.001	.1	.05	.02	.05	.1
Do....................	5.2	0	.01	.1	.005	.05	.02	.02	.008	.01	.02	.01	.05	.002	.005	0	.02	.002	.05	.01	.0005	.15	.03	.015	.02	.1

TABLE 7. - Spectrochemical analyses of coal ash, percent of ash--Continued

State, county, and bed	Ash, percent of dry coal	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Nb (Cb)	Nd	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zn	Zr
West Virginia--Con.																										
Nicholas--Con.																										
Lower Kittanning	7.9	0	.02	.08	.0001	.015	.02	.02	.01	.001	.01	.02	.3	.015	0	.01	.01	.005	.05	.005	.005	.1	.02	.008	.015	.05
Do	8.7	.005	.02	.1	.0005	.015	.03	.02	.01	.0008	.02	.05	.1	.015	.005	.02	.02	.01	.02	.01	.001	.1	.03	.01	.01	.05
Do	4.8	.008	.03	.08	.002	.02	.02	.02	.01	.002	.02	.02	.02	.015	.005	0	.05	.008	.02	.01	.001	.2	.05	.02	.02	.05
Do	10.2	.01	.008	.05	.0008	.01	.004	.008	.004	.0005	.01	.01	.02	.002	.005	0	.01	.004	.005	.008	.001	.1	.02	.005	.04	.07
Sewell	4.2	.01	.01	.1	.001	.02	.02	.05	.008	.002	.01	.05	.02	.015	0	.02	.02	.005	.08	.008	.002	.15	.02	.01	.02	.03
Do	4.3	0	.01	.1	.001	.04	.02	.02	.005	.003	.02	.005	.01	.01	.01	0	.02	.003	.01	.01	.002	.15	.04	.015	.04	.08
Do	2.3	0	.01	.2	.002	.1	.02	.02	.02	.05	.02	.02	.01	.02	.005	.05	.1	.01	.005	.02	.005	.1	.1	.05	.05	.05
Do	6.3	.03	.01	.1	.001	[illegible]	.02	.05	.01	.01	.02	.05	.02	.02	.003	.03	.05	.01	.05	.02	.002	.1	.1	.02	.08	.05
Do	3.7	0	.01	.1	.002	.05	.02	.01	.02	.02	.01	.02	.02	.015	.005	.03	.1	.01	.01	.003	.001	.3	.1	.01	.08	.05
Do	3.2	0	.01	.08	.001	.08	.005	.02	.01	.01	.02	.005	.008	.002	.01	0	.02	.01	.008	.005	.001	.1	.02	.02	.05	.1
Do	2.4	0	.008	.1	.0015	.03	.001	.01	.01	.01	.01	.05	.002	.002	.002	.03	.02	.001	.008	.01	.001	.2	.03	.01	.02	.02
Upper Kittanning	9.5	0	.02	.1	.002	.015	.02	.02	.01	.002	.02	.02	.01	.015	.005	.01	.02	.005	.01	.02	.001	.2	.02	.01	0	.05
Winifrede	8.4	0	.01	.15	.001	.015	.02	.01	.005	.001	.01	.1	.01	.01	.001	0	.02	.001	.008	.015	.0005	.08	.03	.008	.005	.02
Ohio: Pittsburgh	6.7	.02	.2	.05	.001	.01	.1	.01	.01	.005	.01	.01	.1	.01	0	.01	.05	.01	.01	.01	.01	.1	.05	.015	.05	.05
Pocahontas: Sewell	4.9	0	.02	.2	.005	.05	.03	.02	.01	.001	.05	.01	.1	.02	.003	.01	.02	.005	.01	.01	.0005	.2	.03	.05	.01	.05
Preston:																										
Bakerstown	10.6	.02	.02	.1	.0007	.02	.05	.02	.003	.01	.02	.02	.1	.01	.005	0	.03	.002	.001	.003	.0007	.02	.02	.015	.03	.1
Do	1[illegible].3	.05	.005	.05	.0005	.02	.04	.003	.002	.002	.02	.1	.007	.015	.005	0	.01	.002	.01	.01	.0005	.1	.02	.01	.01	.1
Do	9.9	.01	.008	.1	.0001	.01	.02	.008	.001	.005	0	.15	.01	.02	0	0	.01	.0008	.01	.008	.0005	.1	.02	.008	.01	.02
Do	7.3	.01	.005	.01	.0005	.015	.01	.005	.003	.002	.01	.008	.01	.004	.002	0	.01	.0015	0	.01	.001	.05	.02	.005	.02	.07
Do	8.0	.03	.005	.05	.0005	.03	.05	.005	.005	.005	.01	.007	.02	.01	.008	0	.02	.008	.003	.01	.001	.08	.015	.01	.015	.1
Do	10.6	.02	.005	.08	.0008	.01	.02	.01	.004	.01	.015	.008	.05	.01	.004	0	.015	.005	.01	.003	.001	.15	.02	.015	.02	.1
Lower Freeport	15.7	.015	.008	.08	.0002	.008	.02	.008	.002	.001	0	.1	.01	.02	0	.015	.015	.0005	.05	.005	.0003	.1	.02	.005	.02	.015
Do	9.6	.005	.02	.2	.001	.015	.02	.01	.008	.0015	.015	.1	.1	.015	0	.03	.02	.002	.05	.01	.0005	.1	.03	.015	.02	.05
Lower Kittanning	9.5	0	.01	.02	.0008	.02	.01	.015	.005	.001	.02	.01	.001	.002	.01	0	.01	.004	.005	.01	.0005	.1	.02	.01	.1	.1
Do	11.1	.005	.01	.05	.001	.01	.05	.01	.02	.01	.02	.01	.1	.02	.005	.02	.05	.01	.005	.02	.001	.05	.05	.02	.05	.02
Mahoning	17.4	0	.01	.04	.0005	.01	.02	.01	.003	.001	.01	.02	.005	.002	.004	0	.01	.001	.02	.003	.0005	.07	.02	.005	.01	.08
Upper Freeport	13.8	.02	.02	.05	.0005	.02	.02	.005	.005	.0015	.02	.1	.02	.005	.002	0	.005	.002	.01	.01	.0007	.1	.05	.003	.005	.1
Do	8.0	.005	.02	.03	.0008	.015	.05	.015	.01	.001	.02	.01	.05	.02	.005	0	.05	.01	.03	.02	.002	.06	.08	.02	.05	.03
Do	11.2	.009	.005	.03	.0005	.02	.02	.01	.005	.001	.02	.008	.01	.005	.01	0	.03	.003	.015	.015	.0005	.15	.09	.015	.03	.1
Do	16.2	.015	.005	.02	.0005	.015	.02	.003	.003	.0005	.01	.03	.006	.002	.005	0	.02	.002	.01	.007	.0005	.02	.02	.03	.005	.1
Do	22.2	.01	.02	.02	.0005	.01	.02	.007	.002	.0007	.02	.1	.007	.005	.005	0	.01	.0005	.01	.005	.0002	.05	.02	.005	.005	.1
Do	6.6	.01	.01	.05	.0005	.03	.02	.01	.005	.001	.02	.07	.008	.004	.002	0	.02	.003	.01	.02	.0005	.08	.05	.02	.015	.08
Do	22.6	0	.01	.05	.0005	.02	.02	.005	.005	.001	.02	.1	.007	.002	.002	0	.01	.002	.01	.01	.001	.1	.05	.01	.005	.1
Do	7.8	0	.01	.05	.0005	.02	.02	.005	.005	.002	.02	.01	.007	.003	.002	0	.015	.002	.02	.02	.0005	.1	.08	.015	.03	.09
Upper Kittanning	9.3	.02	.01	.02	.002	.03	.03	.02	.02	.01	.01	.015	.02	.02	.005	0	.1	.01	.02	.01	.001	.02	.02	.01	.05	.03
Putnam: Pittsburgh	7.7	.005	.02	.05	.0001	.008	.02	.008	.005	.0005	.01	.05	.03	.015	0	0	.02	.0008	.02	.01	.0005	.1	.03	.008	.005	.05
Raleigh:																										
Beckley	8.5	.02	.01	.1	.001	.015	.015	.01	.008	.002	.02	.015	.005	.001	.005	0	.01	.01	.01	.005	.002	.05	.005	.01	.05	.08
Eagle	7.4	.01	.01	.1	.001	.01	.02	.01	.002	.002	.01	.02	.01	.003	.01	0	.01	.001	.01	.005	.0008	.12	.02	.003	.004	.15
Do	8.1	0	.005	.08	.0005	.005	.005	.02	.005	.001	.01	.02	.001	.001	.005	0	.005	.002	.002	.005	.001	.05	.01	.01	0	.1
Pocahontas No. 3	5.9	0	.01	.05	.002	.02	.05	.03	.01	.01	.01	.2	.02	.01	0	0	.02	.008	.02	.01	.001	.1	.05	.01	.01	.03
Pocahontas No. 4	5.6	.005	.003	.02	.001	.01	.01	.01	.002	.002	.02	.008	.001	.003	.002	0	.008	.003	.01	.01	.0005	.1	.02	.01	.03	.09
Do	6.0	.005	.005	.04	.001	.02	.02	.02	.002	.003	.02	.003	.002	.005	.002	0	.015	.005	.02	.01	.001	.1	.02	.02	.1	.09
Do	5.7	.01	.01	.1	.001	.05	.02	.02	.005	.002	.02	.1	.005	.01	.005	0	.02	.01	.005	.008	.01	.05	.05	.02	.01	.1
Do	6.0	.01	.005	.02	.001	.06	.01	.015	.004	.002	.02	.008	.008	.004	.002	0	.02	.005	.02	.005	.001	.1	.03	.02	.04	.08
Sewell	6.1	.01	.01	.1	.003	.03	.01	.015	.005	.005	.02	.01	.02	.005	.003	0	.02	.004	.02	.02	.001	.1	.1	.02	.015	.08
Randolph:																										
Campbell Creek	3.5	.002	.02	.3	.001	.05	.015	.01	.001	.01	.01	.1	.02	.015	0	.01	.03	.008	.1	0	.0008	.2	.05	.015	.02	.05
Do	2.1	0	.02	.02	.002	.03	.02	.02	.01	.008	.01	.01	.01	.02	0	.03	.02	.005	.005	.008	.0005	.2	.03	.02	.01	.03
Lower Kittanning	9.9	0	.02	.05	.001	.01	.02	.01	.02	.005	.02	.02	.005	.01	.005	.02	.02	.01	.005	.02	.001	.1	.05	.01	.005	.02
Sewell	3.9	0	.015	.1	.001	.03	.02	.01	.01	.008	.02	.02	.015	.015	.002	.03	.02	.008	.05	.015	.0008	.2	.03	.015	.015	.05
Tucker:																										
Upper Freeport	10.6	.01	.02	.03	.001	.015	.08	.02	.01	.001	.01	.02	.02	.01	.002	0	.02	.01	.02	.01	.0008	.06	.05	.008	.05	.05
Do	12.8	0	.008	.1	.0008	.015	.03	.008	.01	.003	.015	.08	.015	.015	.008	.03	.015	.005	.05	.01	.0005	.1	.03	.015	.02	.08

Upshur:																										
Pittsburgh	10.2	.02	.02	.03	.0005	.01	.05	.01	.01	.005	.01	.006	.1	.05	0	.01	.02	.01	.006	.005	.001	.03	.03	.01	.005	.1
Do	8.7	.005	.02	.05	.0005	.005	.02	.008	.01	.005	.01	.02	.05	.005	.001	0	.01	.008	.002	.005	.005	.05	.02	.01	.005	.05
Redstone	8.3	.01	.02	.1	.0003	.005	.03	.01	.005	.01	.01	.01	.15	.01	0	0	.01	.005	.05	.008	.0015	.05	.05	.01	.02	.1
Do	6.2	.02	.05	.2	.0008	.008	.02	.01	.01	.008	.01	.008	.05	.02	.002	0	.02	.01	.02	.01	.002	.06	.05	.01	.015	.02
Do	7.7	.02	.02	.05	.0008	.008	.02	.005	.01	.01	.01	.01	.1	.015	.002	.01	.02	.005	.01	.005	.002	.1	.02	.01	.02	.05
Do	8.7	.01	.03	.1	.0003	.01	.02	.007	.005	.001	.02	.05	.01	.005	.005	0	.01	.003	.02	.005	.002	.1	.01	.003	.005	.07
Upper Freeport	12.2	.02	.02	.1	.0005	.01	.02	.01	.01	.005	.02	.02	.02	.01	.005	.02	.02	.005	.01	.01	.0005	.1	.05	.01	.05	.02
Upper Kittanning	8.4	.005	.02	.02	.001	.02	.05	.02	.01	.005	.02	.02	.01	.02	.005	.02	.02	.005	.01	.02	.0008	.1	.08	.02	.005	.07
Do	15.0	.005	.02	.02	.0005	.01	.05	.02	.02	.005	.02	.06	.02	.02	.005	0	.1	.01	.04	.02	.002	.06	.1	.002	.02	.05
Webster:																										
Fire Creek	8.0	.005	.02	.02	.005	.1	.05	.02	.01	.015	.05	.1	.01	.01	.005	.01	.02	.01	0	.01	.002	.05	.1	.05	.01	.1
Sewell	5.4	0	.02	.2	.002	.04	.02	.02	.02	.01	.03	.1	.007	.015	.01	0	.02	.005	.005	.01	.001	.1	.05	.02	.02	.1
Do	6.4	.01	.02	.05	.001	.05	.05	.02	.03	.01	.03	.05	.03	.02	.005	.02	.05	.01	.005	.02	.002	.1	.1	.05	.02	.1
Wyoming:																										
Beckley	7.5	.005	.005	.07	.0008	.02	.02	.02	.002	.001	.05	.008	.005	.01	.004	0	.02	.004	.008	.02	.0005	.1	.04	.02	.04	.1
Chilton	13.1	0	.01	.1	.0001	.01	.01	.01	.005	.001	.01	.1	.02	.002	0	0	.01	.005	.15	.01	.0005	.2	.03	.01	.01	.015
Douglas	4.6	.015	.01	.15	.005	.01	.01	.01	.005	.01	.01	.05	.008	.002	.005	0	.02	.003	.008	.005	.001	.1	.05	.02	.02	.08
Eagle	4.9	0	.01	.15	.003	.07	.015	.02	.005	.002	.02	.05	.01	.002	.01	0	.02	.01	.01	.01	.02	.1	.03	.02	.05	.1
Pocahontas No. 4	6.3	.01	.01	.1	.002	.05	.02	.02	.003	.001	.015	.15	.007	.003	.002	0	.02	.003	0	.015	.0005	.1	.1	.03	.005	.2
Powellton	6.5	0	.01	.15	.001	.01	.01	.01	.005	.002	.01	.1	.02	.02	0	0	.01	.005	.08	.008	.0005	.2	.02	.01	.01	.02
Wyoming:																										
Carbon:																										
Unknown	6.4	0	.005	.09	.0001	.005	.005	.002	.002	.0002	0	.005	.02	.001	0	0	.002	.0008	.01	0	.001	.05	.01	.001	.005	.015
Do	14.4	0	.02	.2	.0002	.008	.005	.01	.001	.0002	.005	.01	.008	.005	.002	0	.002	.0002	.003	.003	.0005	.2	.02	.005	0	.02
Sweetwater: No. 11	5.4	0	.1	.3	.008	.005	.01	.003	.002	.005	0	.05	.02	.002	0	0	.01	.001	.02	.005	.002	.1	.02	.01	.08	.1

RARE ELEMENTS IN COAL*

TABLE 1. - Rare elements in ashes of coal and in the earth's crust

[Compiled by Goldschmidt (47)]

Element	Symbol	Maximum percentage in coal ashes	Average percentage of "rich" ashes	Percentage in earth's crust	Factor of enrichment	
					Maximum in coal ashes	Average of "rich" ashes
Beryllium......	Be	0.1	0.03	0.0002 to 0.001	100 to 500	30 to 150
Boron..........	B	0.3	.06	0.0003	1,000	200
Scandium.......	Sc	0.04	.006	0.0003 to 0.0006	70 to 130	10 to 20
Cobalt.........	Co	0.15	.03	0.004	40	8
Nickel.........	Ni	0.8	.07	0.01	80	7
Zinc...........	Zn	1.	-	0.02	50	-
Gallium........	Ga	0.04	.01	0.001 to 0.0015	30 to 40	7 to 10
Germanium......	Ge	1.1	.05	0.0004 to 0.0007	1,600 to 2,800	70 to 120
Arsenic........	As	0.8	.05	0.0005	1,600	100
Yttrium........	Y	0.08	.01	0.001	80	10
Zirconium......	Zr	0.5	-	0.02	25	-
Molybdenum.....	Mo	0.05	.02	0.0015	30	13
Antimony.......	Sb	0.1	.02	-	-	-
Tin............	Sn	0.05	.02	0.005	10	4
Lead...........	Pb	0.1	-	0.0016	70	-
Bismuth........	Bi	0.003	-	-	-	-
Silver.........	Ag	0.0005 to 0.001	.0002	0.00001	50 to 100	20
Gold...........	Au	0.00002 to 0.00005	-	0.0000005	40 to 100	-
Rhodium........	Rh	0.000002	-	-	-	-
Palladium......	Pd	0.00002	-	-	-	-
Platinum.......	Pt	0.00007	-	-	-	-

TABLE 2. - Enrichment of elements during decay of oak and beech humus; percent of ash

[Goldschmidt (47)]

	B_2O_3	MnO	NiO	GeO_2	As_2O_5	Ag	Au
Mineral soil (sand)..............	0.0007	0.04	0.002	0.0005	-	-	-
Ash from fresh oak leaves........	0.5 to 1.0	[1] 2.00	.005	.0005	-	-	-
Ash from oak humus...............	0.02	.24	.01	.007	-	0.0001	-
Ash from beech humus.............	0.003	.14	.01	.007	0.05	.0005	0.00002

[1] Ash from fresh beech leaves; in weathered leaves from previous year, 0.77 percent MnO.

(47) Goldschmidt, V. M., Ind. Eng. Chem. 27, 1100-1102 (1935).

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* Abernethy, R. F. and Gibson, F. H., Bureau of Mines, IC 8163; 1963.

RARE ELEMENTS IN ANALYSES OF ASH

Typical limits of coal-ash analyses of United States bituminous coals

Constituent	Percent
Silica (SiO_2)......................................	20 - 60
Aluminum oxide (Al_2O_3)...........................	10 - 35
Ferric oxide (Fe_2O_3).............................	5 - 35
Calcium oxide (CaO)..................................	1 - 20
Magnesium oxide (MgO)................................	0.3 - 4
Titanium oxide (TiO_2).............................	0.5 - 2.5
Alkalies ($Na_2O + K_2O$)............................	1 - 4
Sulfur trioxide (SO_3).............................	0.1 - 12

Selvig, W. A. and Gibson, F. H., Bureau of Mines, B 567; 1956.

TABLE 3. - Chemical analysis of ash of lignite char from Lehigh, N. Dak., lignite

Constituent	Percent ash, ignited at 800° C	Constituent	Percent of ash, ignited at 800° C
SiO_2..............	20.71	Cl.................	0.124
TiO_2..............	.67	B_2O_3..............	.67
Al_2O_3.............	9.96	BaO................	.166
Fe_2O_3.............	5.41	CuO................	.025
MnO................	.19	ZnO................	.05
CaO................	25.60	Bi_2O_3.............	Trace
MgO................	9.82	V_2O_5..............	Absent
Na_2O..............	2.91		
K_2O...............	.44	Summation..........	99.79
SO_3...............	23.00	Less O for Cl.....	.03
P_2O_5..............	.043	True total........	99.76

Brewer, R. E. and Ryerson, L. H., Ind. Eng. Chem. 27, 1047-1053 (1935).

COMPOSITION OF WEST VIRGINIA COAL ASH

	Column analysis				Cube analysis			Enrichment ratio of coal ash to earth's crust	Earth's crust, percent as oxide (48)
Oxide	Average, percent	Maximum, percent	Minimum, percent	Variance ratio	Maximum, percent	Minimum, percent	Variance ratio		
Li_2O	0.075	0.14	0.024	5	0.66	<0.005	>13	5	0.014
Na_2O	1.78	3.66	.82	4	9.13	.30	30	.47	3.81
K_2O	1.60	2.50	.89	3	4.86	.36	13	.51	3.11
Rb_2O	.030	.055	<.03	>2	.12	<.03	>4	.88	.034
CaO	2.76	12	.81	15	36.3	.12	300	.53	5.07
SrO	.38	1.05	.11	10	12	<.01	>1200	7	.050
BaO	.22	.49	.059	8	1.80	.02	90	5	.043
MgO	.98	1.71	.58	3	3.20	.10	32	.28	3.48
Al_2O_3	29.9	38.7	21.8	2	53.3	2.8	19	1.85	16.7
SiO_2	43.9	55.5	29.2	2	82.6	2.0	41	.75	59.0
Fe_2O_3	15.9	37.8	3.87	9	91.9	1.10	94	2.19	7.26
TiO_2	1.52	2.30	1.00	2	5.73	.17	34	1.47	1.03
Ag_2O	.0010	.003	<.0005	>6	.009	<.0005	>18	100	.00001
As_2O_3	<.07	.075	<.07	>1	.22	<.07	>3	<100	.0007
B_2O_3	.12	.31	.027	11	.66	.017	39	133	.0009
BeO	.008	.030	.002	15	.14	<.0005	>280	4	.0019
Bi_2O_3	<.004	.007	<.004	>2	.10	<.004	>3	<200	.00002
Cb_2O_5	.010	.012	<.007	>2	.022	<.007	>3	3	.0034
CoO	.010	.023	.006	4	.096	<.005	>19	2	.0050
Cr_2O_3	.023	.029	.016	2	.053	.010	5	.79	.029
CuO	.061	.13	.028	5	.53	.006	90	5	.012
GaO	.022	.032	.015	2	.124	.005	25	12	.0019
GeO_2	.011	.026	<.005	>5	.250	<.005	>50	11	.0010
HgO	.011	.021	<.008	>3	.059	<.008	>7	157	.00007
La_2O_3	.030	.051	<.035	>2	.096	<.035	>3	13	.0023
MnO	.046	.23	.016	15	1.16	.006	193	.38	.120
MoO_3	.016	.040	.005	8	.140	<.006	>23	6	.0025
NiO	.047	.10	.016	7	.57	<.005	>11	3.6	.0127
P_2O_5	.35	1.21	<.20	>6	8.35	<.2	>42	1.9	.180
PbO	.048	.14	.020	7	.27	<.015	>28	28	.0017
Sb_2O_3	<.005	<.005	<.005	>1	.028	<.005	>6	<50	.0001
SnO_2	.020	.070	<.01	>7	.190	<.01	>19	4.4	.0045
V_2O_5	.050	.069	.032	2	.15	.014	11	2.8	.018
WO_3	<.01	.019	<.01	>2	.056	<.01	>6	<2	.0087
ZnO	.053	.11	<.05	>2	.24	<.05	>5	10	.0050
ZrO_2	.029	.046	.019	2	.089	.009	10	12	.0025

Headlee, A. J. W. and Hunter, R. G., West Virginia Geological Survey, 13A, 36-122 (1955).

Range of concentration of minor and trace elements[1] in anthracite ash and burning bank samples, percent of ash

Element or oxide	Minimum	Maximum
Titanium oxide (TiO_2)	1.5	2.0
Magnesium oxide (MgO)	.4	.9
Calcium oxide (CaO)	.2	.4
Vanadium oxide (V_2O_5)	.02	.04
Germanium oxide (GeO_2)	Trace	.02
Manganese oxide (MnO)	.006	.008
Arsenic (As)	Trace	.01
Copper (Cu)	.001	.01
Chromium (Cr)	.001	.01
Lead (Pb)	.001	.01
Lithium (Li)	Trace	.01
Phosphorus (P)	-	[2].x
Gallium (Ga), nickel (Ni), tin (Sn), and zinc (Zn)	-	.0x
Beryllium (Be), cobalt (Co), tungsten (W), and molybdenum (Mo)	-	.00x

[1] Some trace elements (Ag, B, Bi, Cd, Hg, La, Sb, Te, Zr) reported by other investigators were not detected in these preliminary studies. More specific examination of the samples for those particular elements may show their presence, but in general the concentration will probably not exceed 0.00x.

x denotes order of magnitude of the element concentration for which the spectrographic lines from the unknown were not within the range of the standard currently available.

Nunn, R. C., et al., Trans. Ann. Anthracite Comp., Lehigh Univ. 11, 51-65 (1953).

Average minor element content in ash and in coal of the Northern Great Plains coal province

Element	Number of determinations	Detections		Individual analysis				Averages of beds				Averages of beds			
				Element in ash, percent			Maximum ÷ minimum	Element in ash, percent			Maximum ÷ minimum	Element in coal, ppm			Maximum ÷ minimum
		Number	Percent	Average	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum	
Be.....	221	197	89.1	0.0025	0.03	<0.0001	>300	0.0018	0.013	<0.0001	>130	1.5	8.2	<0.1	>82
B......	154	154	100	.15	1.0	.002	500	.19	.65	.005	130	116	356	15	24
Ti.....	159	159	100	.59	3.5	.01	350	.65	2.6	.15	17	591	2,320	95	24
V......	221	220	99.5	.065	2.5	<.001	>2,500	.015	.058	<.001	>58	16	59	<1.4	>42
Cr.....	221	212	95.9	.02	.74	<.0001	>7,400	.007	.03	<.0001	>300	7	21	<.1	210
Co.....	221	204	92.3	.004	.05	<.0005	>100	.0021	.009	<.0005	>18	2.7	12	<.4	>30
Ni.....	221	220	99.5	.0087	.24	<.0005	>480	.0064	.059	.0003	197	7.2	40	.42	95
Cu.....	221	221	100	.015	.12	.001	120	.013	.07	.002	35	15	185	2.6	71
Zn.....	221	21	9.5	.018	.7	<.02	>35	.08	.7	<.02	>35	59	1,000	<9	>111
Ga.....	221	214	96.8	.01	.32	<.001	>320	.0047	.016	<.001	>16	5.5	23	<1.4	>16
Ge.....	222	95	42.8	.074	4.7	<.001	>4,700	.0022	.02	<.001	>20	1.6	16	<.4	>40
Mo.....	221	139	62.9	.0025	.03	<.0005	>60	.0016	.0065	<.0005	>13	1.7	4.9	<.7	>7
Sn.....	166	47	28.3	.0027	.14	<.002	>70	.0016	.01	<.002	>5.0	.9	5.6	<.1	>56
Y......	208	189	90.9	.021	.2	<.001	>200	.013	.052	<.001	>52	13	49	<.1	>490
La.....	206	152	73.7	.012	.07	<.003	>23	.011	.036	<.003	>12	9.5	40	<1.5	>27

Zubovic, P., et al., U.S. Survey, Bull. 1117-A, 1961, 58 pp.

Maximum concentration of minor elements detected in samples of coal ash examined

Number of samples	Locality	Range of concentration, percent				
		10-1	1.0 - 0.1	0.1 - 0.01	0.01 - 0.001	0.001 - 0.0001
151	Harding County, S. Dak...	-	B, Ba, Sr, Mn, Ti, Mo, Co, Ni, Zn, As, Pb, Zr, Be, U.	Cu, Cr, V, Li, Y, La, Ga, Ge, Sc.	Sn	Yb, Ag.
59	Perkins County, S. Dak...	-	B, Ba, Sr, P, Ti, Mo, Zr, U.	Cu, Cr, V, Ni, Co, Pb, Mn, Ga, Ge, Zn, La.	Y, Sc, Sn.	Be, Yb, Ag.
26	Bowman County, N. Dak....	-	B, Ba, Sr, Mn, Ti, As, Pb, V, Zr.	Cu, Cr, Mo, Ni, Co, Ga, Ge, U.	Y, Sc, Sn.	Be, Yb.
4	McKenzie County, N. Dak..	-	B, Ba, Sr, Mn, Pb.	Ti, V, Cu, Li, Sn, La, Zr, Co.	Y, Mo, Ga, Ge, Ni, Cr.	Be, Yb.
35	Jefferson County, Colo...	-	B, Ba, Sr, Mn, Ti, Mo, Y.	Cu, Cr, V, Ni, Co, Zr, Pb.	Sn, Sc, Ga, U, Ge, La, Yb, Be.	-
48	Milam County, Tex........	P	B, Ba, Sr, Mn, Ti, Ni, Sn.	Cu, Cr, V, Co, Pb, Zr, Zn, Y.	Mo, Sc, Ga, Ge, Be, Yb.	-

Deul, M. and Annell, C. S., U.S. Geol. Survey, Bull. 1036-H, 1956, pp. 155-172.

Average content of each minor element in coals from three major coal producing areas of the United States, parts per million in coal

Elements	Northern Great Plains province (avg. of 46 bed samples)	Eastern Interior region (avg. of 47 bed samples)	Appalachian region (avg. of 65 bed samples)
Be	1.5	2.5	2.5
B	116	96	25
Ti	590	450	340
V	16	35	21
Cr	7	20	13
Co	2.7	3.8	5.1
Ni	7.2	15	14
Cu	15	11	15
Zn	59	44	7.6
Ga	5.5	4.1	4.9
Ge	1.6	13	5.8
Mo	1.7	4.3	3.5
Sn	.9	1.5	.4
Y	13	7.7	14
La	9.5	5.1	9.4

Zubovic, P., et al., U.S. Geol. Survey Prof. Paper 400-B, 1960, pp B87-B88.

Antimony*

In a study of ash composition of 31 column samples of coal from 15 beds in West Virginia, Headlee and Hunter (61) reported that antimony was below the limit of detection of 0.004 percent. Certain parts of the beds contained some antimony, usually at the top or bottom; the greatest amount found was 0.023 percent.

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* For references on this and following pages, refer to Bureau of Mines IC 8163; 1963.

ARSENIC IN COAL AND COAL ASH

Source of coal	Researchers	Reference*	Percentage of As in coal
United States, 13 samples..	Hertzog.................	(63)	0.00008 to 0.0016
United States, 1 sample....	do.....................	(63)	0.0106
			Percentage of As in coal ash
Pennsylvania, Anthracite...	Hall and Lovell.........	(57)	0.0021 to 0.0055
Do...............	Nunn, Lovell, and Wright	(127)	Up to 0.01
North and South Dakota.....	Duel and Annell.........	(32)	0.1 to 1.0
West Virginia..............	Headlee and Hunter......	(61)	Up to 0.057

BARIUM IN COAL ASH

Source of coal	Researchers	Reference*	Percentage of Ba in ash
West Virginia..............	Headlee and Hunter......	(61)	0.05 to 0.44
North Dakota............	Brewer and Ryerson......	(16)	0.15

For references, see Bureau of Mines IC 8163.

Beryllium

Stadnichenko, Zubovic, and Sheffey (153, 154) studied the geochemistry of beryllium in American coals and results for maximum and minimum averages of beryllium content of coal beds are given in table 14. Their conclusions of the investigation were:

> The study of 1385 samples of coal from most of the coal-producing regions of the United States shows a wide variation in beryllium content. The areal distribution of the sample localities shows beryllium-rich and beryllium-poor regions. The rich and the poor distribution of beryllium in coal beds depends upon the availability of beryllium to the swamps at the time of deposition of the coal. This availability was dependent upon the type of rock being eroded in the surrounding borderlands.
>
> There is also a pattern in the distribution of beryllium in coal in a basin. Coal sampled near the edge of a basin has a higher beryllium content than that sampled in the center. Coal that was deposited near eroding rocks rich in beryllium, or that had access to water from such areas is also high in beryllium.
>
> In sink-float experiments, beryllium is consistently associated with the lighter organic-rich fractions. The beryllium content of the sink fractions, particularly those with a high percentage of ash, consistently is below the average for that of the earth's crust. The analysis of petrographic constituents of coal shows that beryllium is most often associated with vitrain and least with fusain.
>
> The accumulation of beryllium in coal is concluded to be a syngenetic process. The beryllium now present in the coal probably is a result of accumulation by plants and (or) by the adsorption from solution by the organic matter in the coal-forming swamps to form metallo-organic complexes. Although some of the original beryllium may have been lost, there is no possible way to ascertain this. Further studies should be made of coal beds which contain large amounts of beryllium. The economic aspects of the beryllium in coal are not predictable.

The average beryllium content in coal for three major coal producing areas in the United States (181) were:

	ppm
Northern Great Plains.........	1.5
Eastern, Interior.............	2.5
Appalachian region............	2.5

Summary of maximum and minimum averages of beryllium content of coal beds

[Stadnichenko, Zubovic, and Sheffey (154)]

Coal	Maximum beryllium in ash	Average ash of coal	Minimum beryllium in ash	Ash average of coal	Beryllium in coal, ppm		Number of	
	Percent				Maximum	Minimum	Bed averages	Individual samples
Eastern province, Appalachian region								
Northern part:								
Lower Kittanning bed	0.0041	6.06	0.0016	9.85	4.1	1.6	14	104
Middle Kittanning bed	.014	3.02	.0016	11.07	4.2	1.5	6	46
Southern part:								
Alabama	.015	1.71	.0011	4.31	4.6	.5	23	68
Eastern Kentucky	.11	2.85	.001	4.31	31	.4	19	87
Tennessee	.0046	8.91	.0005	2.39	11	.1	7	29
Virginia and West Virginia	.0072	4.99	.0007	6.60	3.6	.2	11	30
Interior province								
Eastern region:								
Illinois (all samples)	0.011	5.72	0.0004	16.21	6.3	0.7	35	253
Bed 5	.011	3.20	.0011	9.52	3.2	1	12	90
Bed 6	.0044	6.28	.0004	16.21	4	.7	12	74
Indiana (all samples)	.017	5.25	.0032	6.30	12	1.5	10	83
Western Kentucky (all samples)	.0093	10.18	.0004	13.05	9.5	.5	17	96
Bed 9	.0057	5.87	.0013	13.28	4.3	1.7	10	47
Western region:								
McAlester Basin	.003	5.02	.0001	4.40	2.9	<.1	18	44
All other	.011	2.72	.0003	16.98	5.1	.5	12	110
Northern Great Plains province								
Jurassic and Cretaceous	0.0094	5.95	0.0015	18.25	5.8	2.7	5	58
Paleocene and Eocene	.013	7.01	<.0001	3.45	9.1	<.1	43	131
Rocky Mountain province								
Sweetwater County, Wyo	0.038	1.72	0.0003	3.38	13	0.1	7	17
All other	.062	4.95	<.0001	5.20	31	<.1	53	174

Beryllium in coal ash

Source of coal	Researchers	Reference	Percentage of Be in ash
United States:			
Pennsylvania, anthracite.	Nunn and others.........	(127)	0.001 to 0.009
Texas, Colorado, North and South Dakota.	Deul and Annell.........	(32)	0.1 to 1.0 max.
West Virginia...........	Headlee and Hunter......	(61)	0.0007 to 0.0108

Bismuth

Headlee and Hunter (61) reported from less than 0.0036 to 0.0063 percent bismuth in ash of West Virginia coals. Variation of bismuth content in the ash from various parts of the coal beds ranged from less than 0.0036 to 0.09 percent.

Boron

Deul and Annell (32) noted that the boron contents of the coals they examined were high, averaging more than 0.1 percent boron in the ash which indicates considerable enrichment over that in the earth's crust. They suggested that boron is perhaps the only element in coal ash which is directly attributable to the plants from which the coal was formed. Goldschmidt (51) noted some enrichment of boron in coal ash,

Source of coal	Researchers	Reference	
Boron in ash, percent			
United States:			
Northern Great Plains...	Zubovic and others.....	(184)	0.005 to 0.65
West Virginia...........	Headlee and Hunter.....	(61)	0.008 to 0.096
North Dakota............	Brewer and Ryerson.....	(16)	0.21
Boron in coal, parts per million			
United States:			
Northern Great Plains...	Zubovic and others.....	(181)	116
Eastern Interior........	do.............	(181)	96
Appalachian.............	do.............	(181)	25

Chlorine

Parr and Wheeler (130) determined chlorine in 49 samples of Illinois coal by digesting pulverized coal with water and titrating with standard silver nitrate solution. The chlorine contents of 32 samples ranged from 0.03 to 0.56 percent, and none was detected in 17 samples.

Selvig and Gibson (145) determined total halogen content by igniting the coal in an oxygen bomb and titrating the chlorine in the bomb washings. The chlorine in 21 coals from various states ranged from 0.01 to 0.46 percent; no chlorine was detected in 3 coals from Western States.

CHROMIUM

Chromium contents reported by various investigators are shown in the following table.

Source of coal	Researchers	Reference	
	Chromium in ash, percent		
United States:			
Northern Great Plains.....	Zubovic and others...	(184)	<0.0001 to 0.03
North Caroline, peat......	Baskerville..........	(4)	0.019 to 0.025
Pennsylvania, anthracite..	Nunn and others......	(127)	0.001 to 0.01
Pennsylvania:			
Cambria County..........	Gibson and Selvig....	(46)	0.027
Washington County.......	do............	(46)	0.013
Texas, Colorado, North and South Dakota.	Deul and Annell......	(32)	0.01 to 0.1
West Virginia............	Headlee and Hunter...	(61)	0.011 to 0.02
	Chromium in coal, parts per million		
United States:			
Northern Great Plains.....	Zubovic and others...	(181)	7
Eastern Interior..........	do..........		20
Appalachian region........	do..........		13

Cobalt

Three major coal producing areas of the United States (181) showed the following average cobalt contents in parts per million; Northern Great Plains, 2.7; Eastern Interior, 3.8; and Appalachian region, 5.1. Cobalt contents of coal ash reported by several investigators are given in the following table.

Source of coal	Researchers	Reference	Co in ash, percent
United States:			
Northern Great Plains.....	Zubovic and others..	(184)	<0.0005 to 0.009
Pennsylvania, anthracite..	Nunn and others.....	(127)	0.001 to 0.009
Texas, Colorado, North and South Dakota.	Deul and Annell.....	(32)	0.01 to 1.0
West Virginia............	Headlee and Hunter..	(61)	0.005 to 0.018

Copper

The average parts per million of copper reported in coal from three areas of the United States (181) were Northern Great Plains, 15; Eastern Interior, 11; and Appalachian Region, 15.

Source of coal	Researchers	Reference	Cu in ash, percent
United States:			
Northern Great Plains.....	Zubovic and others..	(184)	0.002 to 0.07
North Dakota..............	Brewer and Ryerson..	(16)	0.020
Pennsylvania, anthracite..	Nunn and others.....	(127)	0.001 to 0.01
Do...............	Jones and Buller....	(77)	0.03 to 0.07
Texas, Colorado, North and South Dakota.	Deul and Annell.....	(32)	0.01 to 0.1
West Virginia.............	Headlee and Hunter..	(61)	0.022 to 0.10

Fluorine

A sample of southern Illinois coal and a sample of western Pennsylvania coal analyzed by Churchill, Rowley, and Martin (22) contained 167 and 85 parts per million fluorine, respectively. The authors also reported fluorine determinations of six coal samples taken in Vancouver, Washington. Four of the coals were from Utah and the source was not given for two samples; the range of fluorine was 145 to 295 parts per million.

Bradford (12) found 40 to 132 parts per million of fluorine in six western coals used in Utah.

Gold

According to Jenney (76) gold has often been reported in the ash of Cretaceous coals of western United States. An average value of $0.60 to $0.80 gold per ton of ash was recorded for coals from Pleasant Valley, Utah, and Kemmerer, Wyo. Chance (21) and Stone (155) mentioned the occurrence of gold in coal from Cambria, Wyo. The gold content of some of the coal in this area attained a value of $2.00 per ton. Gold was found also in the coke, in ash and soot from the boilers, and in the sandstone roof of the coal bed. In 1896, when coke made at Cambria was selling for $3.50 per ton, samples were taken from 31 cars during a period of 3 weeks and were assayed by the coal company's chemist. The samples showed an average value of $2.46 per ton in gold and $0.28 in silver, calculated with gold at $20 per ounce and silver at $0.65 per ounce. Smelters at Deadwood, S, Dak., that used this coke recovered the gold from the coke and the gold from the ores. Distribution of the gold in the coal was never determined, but it was observed that the splint and bony coal showed a higher gold content than coal having a lower ash content. The gold in the coal was believed to have come from the sandstone roof of the bed, which carried some gold.

Lanthanum

The lanthanum content of 31 column samples of West Virginia coals analyzed by Headlee and Hunter (61) ranged from less than 0.030, the lower limit of detection, to 0.043 percent in the ash. Lanthanum was the only rare earth that could be detected but it was noted that several others may be present in similar concentrations. The maximum concentration in a part of one bed was 0.082 percent lanthanum in the ash.

Deul and Annell (32) reported that lanthanum was not present in percentages high enough to be detected in most of the western coals tested. The maximum concentration detected by a semiquantitative method was in the range of 0.01 to 0.1 percent lanthanum in the ash. De Brito (18) reported a similar maximum concentration in ash of Portuguese anthracites. Butler (19) detected lanthanum in the ash of Svalbard coals. Zubovic, Stadnichenko, and Sheffey (184) reported from less than 0.003 to 0.036 percent lanthanum in ash of coals of the Northern Great Plains coal province. The average content in coals of the Northern Great Plains, Eastern Interior, and Appalachian region was given as 9.5, 5.1, and 9.4 parts per million lanthanum, respectively (181).

Lead

Small quantities of lead detected in coal ash are listed in the following table.

Source of coal	Researchers	Reference	Pb in ash, percent
United States:			
West Virginia.............	Headlee and Hunter..	(61)	0.019 to 0.13
Texas, Colorado, North and South Dakota.	Deul and Annell.....	(32)	0.01 to 0.1
Pennsylvania, anthracite..	Nunn and others.....	(127)	0.001 to 0.01

Hinds (66) and Jenney (76) reported occurrences of galena (PbS) associated with certain Missouri coals in which the coal obviously had been mineralized by ore-bearing waters.

Lithium

The lithium content of representative West Virginia coal beds (61) calculated as percentage of lithium in the ash, averaged 0.035 with a range of 0.01 to 0.065 percent. The concentration in ash from various parts of the beds ranged from a minimum of less than 0.002 to a maximum of 0.31 percent. The ash of Pennsylvania anthracites contained from a trace to 0.01 percent lithium (127).

In most of the western coal ashes tested, the lithium (32) was not present in percentages high enough to be detected. The maximum concentration was in the range of 0.01 to 0.1 percent.

Manganese

Small quantities of manganese occur in all coal ashes. Manganese is shown qualitatively by the bluish-green color of the sodium carbonate fusion noted frequently in analyses of ash by wet chemical methods. Manganese is a relatively common element, its crustal abundance being 0.10 percent (42). Several determinations of manganese in ash of coals from the United States and other countries that have been reported are shown in the following table.

Source of coal	Researchers	Reference	Mn in ash, percent
United States:			
West Virginia..........	Headlee and Hunter.....	(61)	0.012 to 0.18
Pennsylvania, anthracite.	Nunn, Lovell and Wright	(127)	0.005 to 0.006
Do................	Jones and Buller.......	(77)	0.02 to 0.09
North Dakota...........	Brewer and Ryerson.....	(16)	0.15
Montana................	do..............	(16)	0.33
Alabama, 2 analyses....	Gibson and Selvig......	(46)	0.04 to 0.05
Texas, Colorado, North and South Dakota.	Deul and Annell........	(32)	0.1 to 1.0

Mercury

Headlee and Hunter (61) found that the amount of mercury was below the limits of detection (0.007 percent) in the ashes of most coal from beds in northern West Virginia. The range for all column samples was <0.007 to 0.019 percent mercury in ash with an average of 0.010 percent. Maximum concentration in parts of a bed was 0.055 percent.

The amount of mercury was below the limit of detection (0.1 percent) in ash of western coals tested by Deul and Annell (32).

Molybdenum

Molybdenum contents of coal ash reported by various investigators are shown in the following table.

Source of coal	Researchers	Reference	
	Molybdenum in ash, percent		
United States:			
Northern Great Plains...	Zubovic and others.....	(184)	<0.0005 to 0.0065
Texas, Colorado, North and South Dakota.	Deul and Annell........	(32)	Max.0.1 to 1.0
South Dakota, Harding County.	do...............	(32)	0.15
West Virginia...........	Headlee and Hunter.....	(61)	0.003 to 0.027
Pennsylvania, anthracite	Nunn, Lovell and Wright	(127)	0.001 to 0.009
	Molybdenum in coal, parts per million		
United States:			
Northern Great Plains...	Zubovic and others.....	(181)	1.7
Eastern Interior........	do.............	(181)	4.3
Appalachian Area........	do.............	(181)	3.5

Korolev (92) investigated the causes of the irregular accumulation of molybdenum in coals and concluded that for a given type of coal, in which molybdenum is not directly bound by organic matter, its accumulation depends to a great extent on the intensity of the reduction process. The occurrence of molybdenum in Everglades peat was investigated (41), molybdenum was detected in coal from Belgium (79, 81), and ter Meulen found 0.21 parts per million in coal (110).

NICKEL

Nickel contents of coal ashes reported by various investigators are given in the following table.

Source of coal	Researchers	Reference	Ni in ash, percent
United States:			
Northern Great Plains..	Zubovic and others.....	(184)	0.0003 to 0.059
Texas, Colorado, North and South Dakota.	Deul and Annell........	(32)	0.01 to 1.0
South Dakota...........	do................	(32)	0.12
West Virginia..........	Headlee and Hunter.....	(61)	0.013 to 0.079
Pennsylvania, anthracite.	Nunn, Lovell and Wright	(127)	0.01 to 0.09

Phosphorus

Geer, Davis, and Yancey (45) investigated the manner in which phosphorus occurs in coking coals of Washington and found that the phosphorus content of coal from two beds could be reduced greatly by coal-washing methods. Coal from the west No. 3 bed at Wilkeson, Pierce County, containing 32.6 percent ash and 0.132 percent phosphorus could be washed to produce a product containing 12.1 percent ash and 0.043 percent phosphorus. This result was accomplished with a full-sized coal-washing table, a refuse product containing 59.3 percent ash and 0.358 phosphorus being removed. Coal from the east No. 2 bed at Wilkeson, containing 22.6 percent ash and 0.206 percent phosphorus, was difficult to wash because it contained a large amount of intermediate-density material. By discarding a middling as well as a refuse product, a washed coal was produced that contained 12.0 percent ash and 0.068 percent phosphorus. The phosphorus in coal from five other beds examined could not be reduced appreciably by washing, because it was associated with the clean coal rather than with impurities.

Two phosphorus minerals, evansite ($3\ Al_2O_3.P_2O_5.18\ H_2C$) and wavellite ($3\ Al_2O_3.\ 2\ P_2O_5.\ 13\ H_2O$) were identified in shale from the middle parting of the Roslyn bed by a petrographic examination. About 12 percent of the total phosphorus in the shale occurred in the form of these minerals, but the form in which the remaining 88 percent of the phosphorus occurred could not be determined petrographically. Selvig and Seaman (146) investigated the distribution of ash-forming mineral matter in coal from the Pittsburgh bed, Fayette County, Pa. They reported that the top 10 inches of coal contained relatively large amounts of phosphorus compared to the other benches of the bed. A recalculation of their data to the percentage of phosphorus in the coal shows that bed samples from four locations in a mine contained 0.012 to 0.020 percent phosphorus. In comparison, four samples of the top 10 inches of coal contained 0.024 to 0.092 percent phosphorus.

Phosphorus content of several coals is given in the table of the next page to show the wide variation in percentage of this element in various coals.

Phosphorus in coal

Laboratory number	State	County	Bed	Phosphorus, percentage of coal as received
44579	Alaska	Lower Matanuska District.	Upper Shaw	0.143
36233	Alabama	Tuscaloosa	Milldale	.034
49301	Illinois	Christian	-	.016
37911	do	Williamson	No. 6	.007
38121	do	do	do	.002
39092	Kentucky	Harlan	High Splint	.002
37532	Maryland	Allegany	Big Vein	.017
49460	North Dakota	Mercer	-	.005
37792	Ohio	Belmont	Pittsburgh No. 8	.006
38085	do	Jefferson	do	.009
37599	do	Meigs	Redstone	.009
40047	Pennsylvania	Allegheny	Pittsburgh	.010
41895	do	do	do	.006
37607	do	Cambria	Lower Kittanning	.003
37558	do	Clearfield	do	.005
38622	do	Fayette	Pittsburgh	.012
38638	do	do	do	.020
40044	do	do	do	.016
40045	do	do	do	.014
37530	do	Somerset	Lower Kittanning	.122
37559	do	do	Upper Kittanning	.004
38237	do	do	Lower Kittanning	.012
38293	do	Westmoreland	Pittsburgh	.018
42663	do	do	do	.009
42664	do	do	do	.007
49459	Texas	Milam	-	.004
49382	Utah	Carbon	-	.003
49383	do	do	-	.015
49373	Washington	Pierce	Wilkeson	.052
37983	West Virginia	-	(New River coal)	.004
37984	do	-	(Pocahontas coal)	.002
38105	do	Raleigh	Beckley	.006

Rubidium

Little information is available on the rubidium content of coal. Headlee and Hunter (61) found that the ash of column samples of West Virginia coals contained from a minimum of less than 0.027 percent rubidium, the lower limit of detection, to a maximum of 0.050 percent with an average of 0.027 percent. Maximum content found in ash of cube samples from the coal columns was 0.11 percent.

Silver

Deposits of silver ore at Silver Reef, Washington County, Utah, according to Jenney (76) were mainly due to the reducing action of wood and plant remains more or less altered to lignite. These ores were mined extensively in 1877-79. In places, the ore was very rich, and small deposits of lignite were found in the soft sandstone with native silver in thin scales on the joints of the coal.

Silver was detected in only a few coal ashes from western coals examined by Deul and Annell (32); the maximum amount found was 0.0001 to 0.001 percent.

Headlee and Hunter (61) found more silver in northern than in southern coals of West Virginia; they reported an average of 0.0009 percent silver in ash with a range from <0.0005 to 0.0028 percent. Maximum concentration reported in the ash of coal cubes from the columns was 0.0084 percent.

Strontium

Headlee and Hunter (61) found the strontium content of ash from 31 column samples of West Virginia coals ranged from 0.09 to 0.89 percent, and averaged 0.32 percent. Individual cube samples cut from the columns showed strontium contents ranging from <0.008 to 10.1 percent of ash.

Semiquantitative spectrographic analyses by Deul and Annell (32) of western coals showed a maximum concentration of 0.1 to 1.0 percent strontium in the ash. Chemical analysis of one sample of lignite ash from Harding County, S. Dak., showed 0.45 percent strontium.

Tin

Deul and Annell (32) reported that tin showed an erratic distribution pattern in the coals they examined. It was detected in only 7 of 151 samples from Harding County, S. Dak., but was found in all 48 samples collected in Milam County, Tex., and 5 of these samples contained from 0.1 to 1.0 percent.

Headlee and Hunter (61) found that tin content in ash from 7 of the 31 column samples examined from West Virginia was less than the limit of detection of 0.008 percent tin, and that the southern coals were richer in tin than the northern coals. Bed averages ranged from less than 0.008 to 0.055 percent tin in the ash.

Average amounts of tin found in coals from the Northern Great Plains, Eastern Interior, and Appalachian regions were 0.9, 1.5, and 0.4 parts per million respectively (181).

Other analyses of coal ash are shown in the following table.

Source of coal	Researchers	Reference	Sn in ash, percent
United States:			
Northern Great Plains....	Zubovic and others...	(184)	<0.002 to 0.01
Pennsylvania, anthracite.	Nunn and others......	(127)	0.01 to 0.09

Titanium

Titanium is widely distributed in the earth's crust and according to Fleischer (42), stands ninth in order of abundance, or below magnesium. Wait (170) reported the occurrence of titanium in the ash of some vegetable matters and in coal ash. He found from 0.006 percent titanium in the ash of cow peas to 0.19 percent in the ash of oak wood and from 0.41 to 1.55 percent in five coal ashes. Baskerville (4) reported analyses of three samples of ash from North Carolina peat ranging from 0.20 to 0.29 percent titanium.

Analyses of ash from United States coals published by the Bureau of Mines (144) included the determination of titanium in 116 samples. All of the results calculated as titanium were within the range of 0.3 to 1.5 percent except for 5 samples that had a slightly higher content ranging up to 2.2 percent. Headlee and Hunter (61) obtained similar values for titanium in ash of West Virginia coals, the average being 0.91 percent with a range of 0.60 to 1.38 percent. Analyses of ash of cubes from column samples of coal showed a wider range, the minimum being 0.10 percent and the maximum 3.44 percent. Deul and Annell (32) found titanium was present in the ash of western coals in about the same abundance as in the earth's crust, the maximum concentration being from 0.1 to 1.0 percent Ti. Zubovic, Stadnichenko, and Sheffey (184) reported from 0.15 to 2.6 percent titanium in ash of coals from the Northern Great Plains. Jones and Buller (77) reported 0.58 to 1.09 percent titanium in anthracite ash from Pennsylvania. Nunn, Lovell, and Wright (127) found 0.9 to 1.2 percent titanium in ash from Pennsylvania anthracites.

Tungsten

Little information is available on the amount of tungsten in coal ash. Headlee and Hunter (61) reported that tungsten was below the limit of detection (0.008 percent) in ash from the southern and several of the northern West Virginia coals they tested. The maximum bed average detected was 0.015 percent tungsten in the ash. Analyses of cube samples from a column of the Lower Kittanning bed gave the maximum of 0.044 percent tungsten in the ash.

Nunn, Lovell, and Wright (127) found that the tungsten content in ash from Pennsylvania anthracites ranged from 0.001 to 0.009 percent. In tests of western coals Deul and Annell (32) reported that the tungsten content of ash was below the sensitivity of the method (0.1 percent).

Vanadium

Ash of two Pennsylvania anthracites were analyzed for vanadium by the Bureau of Mines with results as follows.

Source of coal	Ash, percent	V in ash, percent
United States: Pennsylvania:		
Schuylkill County:		
Buck Mountain bed...............	16.0	0.11
Diamond bed......................	10.2	.09

Vanadium in coal and coal ash

Source of coal	Researchers	Reference	
	Vanadium in ash, percent		
United States:			
Northern Great Plains.	Zubovic and others.......	(184)	<0.001 to 0.058
Texas, Colorado, North and South Dakota.	Deul and Annell..........	(32)	0.01 to 0.1
West Virginia.........	Headlee and Hunter.......	(61)	0.018 to 0.039
Pennsylvania, anthracite.	Nunn, Lovell, and Wright.	(127)	0.01 to 0.02
North Carolina, peat..	Baskerville..............	(4)	0.0006 to 0.0017
	Vanadium in coal, parts per million		
United States:			
Northern Great Plains.	Zubovic and others.......	(181)	16
Eastern Interior region.	do...............	(181)	35
Appalachian region....	do...............	(181)	21

Yttrium

From less than 0.001 to 0.052 percent yttrium was reported in ash of coals from the Northern Great Plains (184). Deul and Annell (32) detected a maximum of more than 0.1 percent in the ash of certain western coals, but the range was usually 0.001 to 0.01 percent.

Zinc

Although zinc is considered a minor constituent of coal ash, a sample of coal from Crittenden County, Ky., analyzed by the Bureau of Mines (144) contained 1.6 percent zinc in the ash. The ash of another sample from Hopkins County, Ky., contained 0.16 percent zinc. Headlee and Hunter (61) in their examination of ash constituents of West Virginia coals reported an average of 0.043 percent zinc in the ash with a maximum of 0.19 percent. Examination of the ash of western coals (32) showed that zinc was not present in percentages high enough to be detected (0.01 percent). Zinc was detected in 21 out of 221 coal ash samples tested from Northern Great Plains (184). The limit of detection was 0.02 percent and up to 0.7 percent zinc in ash was reported.

Zinc sulfide was reported to be associated with certain coal deposits in Missouri (66, 76). The large amounts found show that the coal had been mineralized by ore bearing fluids. A zinc-bearing peat deposit in New York was described (20). Sphalerite (ZnS) was identified (33) in nodules of pyrite-marcasite in shale immediately above the coal in the No. 6 bed at Bichnell, Ind.; the pyrite-marcasite was estimated to contain 0.27 percent sphalerite. Sphalerite was identified also in an English coal from Leicestershire (9).

Zirconium

Goldschmidt (47) reported that some coal ashes may contain as much as 0.5 percent zirconium. The zirconium content of ashes examined by Deul and Annell (32) was highly variable, ranging from less than 0.001 to more than 0.1 percent. A sample of South Dakota lignite ash analyzed chemically contained 0.20 percent zirconium. Headlee and Hunter (61) reported that ash from column samples of West Virginia coals contained from 0.014 to 0.034 percent zirconium with a maximum of 0.066 percent zirconium in ash from cube samples cut from the columns.

OCCURRENCE OF GERMANIUM AND GALLIUM

Development of germanium transistors by the electronics industry in 1948 increased demand for the metal and created almost a world-wide interest in coal as a possible new source of germanium. Although most of the production of germanium was from by-products of smelting zinc ore (106) small quantities were known to occur in coal (23, 70). In the United States the Geological Survey (99, 101) tested ash samples from about 700 coals and detected germanium in more than half of the samples. The richest commercial coal, which contained up to 0.2 percent germanium in the ash, was found in the bottom layer of the Lower Kittanning bed in Ohio.

Some evidence was found of distribution by coal components, the bright woody coal (vitrain) often containing more germanium than the fusain. Coalified logs and pieces of woody coal occurring in isolated sediments from the District of Columbia and vicinity contained 2 to 9 percent germanium (100) along with vanadium, chromium, copper and 0.03 to 0.2 percent gallium. However, some coal beds in Western States contained very little germanium in spite of being rich in woody coal which suggests there may be some regional variations in abundance of germanium.

Breger and Schopf (9) reported up to 4 percent germanium in the ash of coalified logs found in the Chattanooga shale in Tennessee and in the Ohio shale. A related occurrence was reported in Japan where lignitic logs associated with lignite beds contained more germanium than the beds. One sample of lignitic log from the Tsukidote area was reported to contain 1,970 parts per million germanium on the ash-free, dry basis (78, 79). Bed samples of lignite contained a maximum of 357 parts per million (77).

Headlee and Hunter (40, 39), used a quantitative spectrographic method, and determined germanium in 35 column samples of West Virginia coals representing 16 coal beds. The germanium content of ash in cubes cut from the column samples ranged from less than 0.003 percent, the lower limit of detection, to 0.17 percent in ash from the top 1-inch cube of a column from the Sewell bed. Average GeO_2 content of the coal columns computed as parts per million in ash-free coal ranged from 0.4 to 31 or 0.3 to 22 parts per million of germanium. Top and bottom layers of most of the column samples contained more germanium than the remainder of the bed. Other investigators (59, 92, 101) noted a similar preferential distribution of germanium in coal beds.

The Bureau of Mines (14, 15), investigated the occurrence and distribution of germanium in the stoker ash and fly ash from coal-fired steam boilers. Thirteen boilers were tested that included slag tap and dry bottom pulverized coal furnaces, cyclone-fired furnaces, and those having underfeed and traveling grate stokers. Results showed that much of the germanium present in the coal is concentrated in the fine fly ash leaving the boiler. Usually no germanium was found in the slag or refuse from the furnaces or in the stoker ash. In those tests where samples were obtained from the dust-collector hoppers, the germanium content of the fly ash ranged from 15 to 60 parts per million, whereas the germanium content of the coal fired ranged from 2.4 to 9 parts per million. A sample of fly ash from a cyclone furnace contained 290 parts per million of germanium and one from a furnace fired with a chain-grate stoker contained 530 parts per million. The concentration of germanium in these two samples was ascribed to the relatively small proportion of ash discharged as fly dust. Although a considerable quantity of germanium is potentially available from the fly ash from some furnaces, the Bureau researchers concluded at the time of the investigation that the concentration generally was too low for fly ash to be considered a commercial source of germanium. They suggested that attention be directed toward methods of coal utilization that tend to concentrate the germanium in the products of combustion. Work in England (25, 41) also indicated that more enrichment of germanium in flue dust may occur in traveling-grate and stoker-fired furnaces than with pulverized-coal firing. Recirculation of fly ash in traveling-grate furnaces was studied in Czechoslovakia as a means of producing a product enriched in germanium (17).

Analyses by the Illinois Geological Survey (71) of 34 samples of fly ash from public utility power plants ranged from 28 to 319 parts per million germanium. Spectrographic analyses of ashes from 24 samples of Kansas coals (94) ranged from 36 to 680 parts per million germanium in the ash or 7 to 48 parts per million in the coal. A second series of 117 samples of ash from Kansas coals (93) showed a maximum of 1,070 parts per million germanium in the ash (116 parts per million in coal) but only 27 of these samples contained more than 200 parts per million germanium in the ash.

Germanium contents reported in coal or in coal ash from various sources, expressed as parts per million, are shown in the following table.

Source of coal	Researchers	Reference	Amount, ppm
	Germanium in coal		
United States:			
Northern Great Plains......	Zubovic and others........	[1](181)	1.6
Eastern Interior...........	do.................	[1](181)	13
Appalachian Region.........	do.................	[1](181)	5.8
Kansas.....................	Schleicher................	(93)	116 max.
West Virginia..............	Headlee and Hunter........	(40)	0.3 to 22
	Germanium in ash		
United States:			
Northern Great Plains......	Zubovic and others........	[1](184)	<10 to 200
Colorado, Texas, North and South Dakota.	Deul and Annell...........	[1](32)	10 to 100
Kansas.....................	Schleicher................	(93)	1,070 max.
Ohio.......................	Stadnichenko and others...	(101)	2,000 max.
Pennsylvania, anthracite...	Nunn and others...........	[1](127)	Trace to 139
West Virginia..............	Headlee and Hunter........	[1](61)	<35 to 180

From the extensive studies of germanium in coal, Fisher (22) suggested several conclusions as follows:

1. Coals with a high vitrain (woody coal) content are much richer in germanium than coal with a low-vitrain content.

2. Low-ash coals are richer in germanium than coals with a high-ash content.

3. Geologically older coals usually have a lower germanium content than more recent coals.

4. Germanium is believed to be associated with the organic matter and not the mineral matter in coal.

5. Germanium is usually concentrated in the top or bottom few inches of coal beds.

OCCURRENCE OF URANIUM

Uranium in association with western United States coals was first identified in a mineralized section of a coal mine near Denver, Colo., by Berthoud in 1875 (7).[7] He reported the coal contained from 0.2 to 2 percent uranium. Later in 1922, Wilson (77) found some carnotite in fractured and partly silicified coal on a dump at the cite of the old workings, but unsilicified coal from a bed nearby contained only 0.064 percent uranium. Six core samples from the coal bed analyzed by Dude and McKeown (30) in 1953 showed a range of 0.001 to 0.10 percent uranium in five of the cores and slightly more than 0.1 percent in one sample. The mineralized coal containing uranium apparently occurred in only specimen amounts.

From measurements of gamma activity, the content of radioactive elements in coal generally is less than in common sedimentary rocks (17, 18). Davidson and Ponsford (19) mentioned the low radioactivity of most coals and reviewed the occurrence of uranium in some exceptional, more highly radioactive coals found in the United States and in Europe.

Search for new sources of uranium led to the discovery that it occurred in certain coals in the Rocky Mountain region (20, 21, 46). According to Kehn (37), some of these coal deposits contain from 0.005 to about 0.01 percent uranium, and local areas may contain larger quantities. Investigations by the U.S. Geological Survey suggest that lignites may contain the most uranium, and subbituminous B and C coals the next largest concentration. Uranium-bearing lignite occurs in the Northern Great Plains, southern Idaho, Nevada, and southern California. Uranium-bearing coal is present in Wyoming, Colorado, New Mexico, and southeastern Idaho. The higher rank bituminous coals and anthracite of the central and eastern United States rarely contain more than 0.001 percent uranium.

Some data from the literature with concentrations expressed as percent uranium in coal are given in the table on page 29.

A number of investigations in the United States were reported on the geochemistry of uranium in coal (9, 10, 11, 12, 22, 73). U.S. Geological Survey Bulletin 1055, containing 10 chapters by various authors, gives data on uranium content of coals of different ages, estimates of the known reserves of uranium-bearing coals, and describes geologic features of the coal beds.

Three hypotheses advanced to explain the occurrence of uranium in some coals were described by Denson (20), as follows:

1. Syngenetic. - Uranium was deposited from surface waters by living plants or in dead organic matter in swamps prior to coalification.

2. Diagenetic. - Uranium was introduced into the coal during coalification by waters bringing the uranium from areas marginal to the coal deposits or from the consolidating enclosing sediments.

Uranium in coal

Source of coal	Researchers	Reference	Percentage of U in coal
United States:			
California...............	Moore and Stephens.........	(49)	0.02 max.
Idaho:			
Bonneville County......	Vine......................	(70,71)	0.02 avg.
Do.............	Vine and Moore............	(72)	0.13 max.
Cassia County..........	Gray......................	(29)	0.0 to 0.1
Do.............	Mapel and Hail............	(42)	0.097 max.
Illinois................	Patterson.................	(55)	<0.001 to 0.008
Indiana.................	Snider....................	(61)	0.001
Montana.................	Gill......................	(27)	0.001 to 0.034
Do..................	Hail and Gill.............	(31)	0.013 max.
Nevada:			
Esmeralda County.......	Moore and Stephens.........	(49)	0.003
Churchill County.......	Lovering..................	(41)	0.059
New Mexico, Sandoval County.	Bachman and others.........	(5, 4)	0.001 to 0.62
North Dakota.............	Moore, Melin, and Kepferle.	(48)	0.045 max.
Do..................	Bergstrom.................	(6)	0.14 max.
Ohio.....................	Snider....................	(60)	0.001
Pennsylvania.............	Ferm......................	(25)	0.002 to 0.014
Do..................	Patterson.................	(53)	0.019 max.
Pennsylvania, anthracite.	Welch.....................	(75)	0.001
South Dakota.............	King and Young............	(39)	0.08 to 0.73
Do..................	Denson, Bachman, and Zeller	(22)	0.005 to 0.02
Do..................	Zeller and Schopf..........	(82)	0.01
Do..................	Gill, Zeller, and Schopf...	(28)	0.005 avg.
Utah.....................	Zeller....................	(81)	0.002
Northern West Virginia...	Patterson.................	(54)	<0.001 to 0.003
Southern West Virginia and Eastern Kentucky.	Welch.....................	(76)	0.001
Southern West Virginia and Southwestern Virginia.	Snider....................	(62)	<0.001
Wyoming..................	Masursky..................	(44)	0.001 to 0.051
Do..................	Breger and others..........	(11)	0.0022
Do..................	Pipiringos................	(57)	0.003 to 0.016
Do..................	Masursky and Pipiringos....	(45)	0.001 to 0.014
Do..................	Love......................	(40)	0.10 max.
Do..................	Wyant, Sharp, and Sheridan.	(80)	0.002 to 0.007

3. Epigenetic. - Uranium was introduced in the coal after coalification and after consolidation of the enclosing sediments by ground water deriving uranium from hydrothermal sources or from unconformably overlying volcanic rocks.

The accumulation of uranium in coal may vary markedly from place to place, and the occurrence of uranium in each deposit should be interpreted in relation to the geologic history of the region. Field evidence favors the epigenetic hypothesis of origin of uranium in western coals. Secondary concentration of uranium in coal may occur when solution of small quantities of uranium by ground water from overlying volcanic rocks is followed by downward percolation of these waters through pervious strata until the uranium is taken up and retained by the highest of the underlying lignite beds (22, 23). Application of this theory led to the discovery of uranium-bearing coal in Wyoming (40), Montana (27), Idaho (42, 71), and New Mexico (5). In general, the uranium-bearing coal in each of these areas forms the topmost coal bed of a sequence overlain unconformably by layers of silicic volcanic materials or other strata from which uranium may have been leached by ground waters. The uranium content of succeeding lower coal beds decreases to the vanishing point. The enrichment of uranium in coals which lie near the erosion zone of granite mountains was noted also in Hungary (26, 66).

Uranium-bearing coal classified as subbituminous B occurs in the Red Desert area, Sweetwater County, Wyo. (44, 47). Masursky and Pipiringos (45) note that the greatest concentration of uranium in the coal occurs locally where the beds are overlain by conglomerate of Miocene age. Widespread but lesser concentrations of uranium occur in coal that is in proximity to permeable sandstone strata. The close relationship between uranium concentration in the coal and permeability of adjacent rocks indicate that the uranium is of epigenetic origin.

Several investigations showed that uranium in coal occurs as an organo-uranium complex soluble at a pH less than 2.18, that distinct uranium minerals rarely are present, and that little of the element is retained by ion exchange (11, 12). Organic material may serve as a reducing agent converting the soluble uranyl ion to an insoluble uranous form, sulfide ion associated with carbonaceous substances may act as a reducing agent, and uranium may be precipitated as insoluble humates. Szalay (64, 65) concluded that humic acids are important agents responsible for the enrichment of uranium in peat and found that a pH of less than three was required to liberate uranium from Hungarian brown coal. Almassy (1) also suggested that uranium in coal is bound by the humic acids. Humic acids and humic matter readily remove uranium from solution (63, 73), and Moore (47) found that subbituminous coal, lignite, and peat readily absorb uranium from solution. Tolmachov (68) demonstrated that activated charcoal and carbonaceous shale remove uranium from uranyl nitrate solution. Extraction of uranium from coal by different solutions and the reaction of humic acid with uranyl salts was investigated by Voskresenskaya (74). Work in Japan showed that the capacity of lignite for absorbing uranium was increased by prolonged oxidation (36). Hoffman (33) found that the uranium content of slightly petrified plants was the same as for living plants.

Preliminary study of the occurrence and distribution of other elements in uranium-bearing coals indicates that only molybdenum shows a consistent relationship to uranium (82).

Denson (20) mentioned that several uranium minerals including autunite, zeunerite, torbernite, carnotite, becquerelite, and coffinite have been identified in some coals that had relatively high contents of uranium, but much of the uranium is inconspicuously disseminated in the carbonaceous material. Individual uranium minerals have not been identified in the more abundant and usual types of uranium-bearing coals. Nekrasova (51, 52) found that certain coals contain uranium partly in the form of typical oxides and partly in a finely dispersed unidentifiable form.

Petrographic study (59, 29) of uraniferous coals in the United States did not establish any correlation between uranium content and the coal components, but did indicate a relationship between high-uranium content and samples rich in humic matter. Some vitrains from coalified wood containing uranium showed chemical and physical properties that differed from normal vitrinites (24).

Botanical prospecting in New Mexico indicated certain areas should be explored further for uranium-bearing coal deposits (15, 16). Breger and his coworkers (13) investigated the effect of dry distillation on uranium associated with coal and other carbonaceous substances and concluded that distillation at 800° C caused no appreciable loss of uranium by volatilization.

These investigations show that uraniferous coals and lignites in the Western States are a potential reserve of large quantities of uranium, although most of the deposits are of low grade with respect to uranium content. Denson (20) noted that recovery of uranium as a byproduct from ash depends on the coals' suitability for use as fuel in competition with other coals. The higher grade uraniferous coals often have greater ash content and lower heating value than nonuraniferous coals. However, many of the known coal deposits containing uranium are suited to strip mining methods.

A local deposit of lignite in Harding County, S. Dak., (8, 38, 39) contained enough uranium to be considered an ore rather than a fuel. The uranium content of 600 tons shipped from Harding County ranged from 0.08 to 0.73 percent uranium and averaged 0.33 percent. Other deposits of lignite containing more than 0.1 percent uranium have been found in the Dakotas, indicating that uranium-bearing coal or lignite of comparable grade may occur at other localities in the Western States.

Methods of recovering uranium from lignite were investigated (43, 58, 79). Processes studied included acid-leaching of ash, roasting with a sulfide of iron, copper, or zinc followed by leaching with water or dilute acid and recovery of uranium from solution by precipitation, ion exchange, or solvent extraction. Acid-leaching of lignite followed by solvent extraction with bis (2-ethylhexyl) phosphoric acid showed promise for samples containing a minimum of acid-soluble organic compounds.

MERCURY IN COAL

TABLE 1. - "Best" values of coals analyzed(1)

Coal			Best value (µg Hg/g coal)	Number of values averaged
Source	Type of mine	Treatment		
EASTERN COALS				
Belmont County, Ohio, No. 9.	Strip..	Raw.......	0.15 ±0.03	32
Harrison County, Ohio, No. 6-A.	Deep...	....do....	.41 ± .06	28
Jefferson County, Ohio, Pgh. No. 8.	Strip..	Washed....	.24 ± .04	30
Kanawha County, W. Va., Hernshaw.	Deep...	....do....	.07 ± .02	27
Washington County, Pa., Pittsburgh seam.	..do...	....do....	.12 ± .04	29
Clay County, Ind., Ind. No. 3.	Strip..	....do....	.07 ± .02	23
Muhlenberg County, Ky., W. Ky. No. 9.	..do...	Raw.......	.19 ± .03	30
WESTERN COALS				
Rosebud County, Mont., Rosebud.	Strip..	Raw.......	0.061±0.007	22
Henry County, Mo., Tebo/Weir.	..do...	Washed/raw	.16 ± .06	37
Montrose County, Colo., Nucla.	..do...	Raw.......	.05 ± .01	29
Navajo County, Ariz., Red Seam.	..do...	....do....	.06 ± .01	26

(1) Schlesinger, M. D. and Schultz, H., Bureau of Mines, RI 7609; 1972.

TABLE 2. - Evaluation of data

Method	Total values submitted	Total values rejected	Percent of total rejected	Percent rejected as high	Percent rejected as low
A. Dissolution and atomic absorption.............	128	23	18	9.4	8.6
B. Combustion and atomic absorption.............	95	31	33	29.5	3.2
C. Activation analysis......	100	3	3	1	2
D-1. Single Ag amalgamation and atomic absorption...	44	8	18	6.8	11.3
D-2. Double Au amalgamation and atomic absorption...	[1]11	0	0	0	0

[1] Each value is an average of at least 4 determinations.

ABSTRACT

Mercury exists in coal in minute quantities, but the large tonnages of coal consumed could represent relatively large amounts of mercury entering the environment. Limits have now been placed on the emission of mercury, and it is important that reliable analytical methods be available to the chemist.

The Bureau of Mines has evaluated analytical techniques used by a number of laboratories; most used vapor phase atomic absorption as the final detection method. Neutron activation was used by some of the laboratories. All of the methods described could be applied, but they require careful manipulation to prevent loss or mercury contamination. In the samples analyzed the mercury content ranged between 0.05±0.01 and 0.41±0.06 part per million.

COAL SAMPLING AND EXPERIMENTAL DESIGN

Eleven samples of coal were obtained from active coal mines that deliver large tonnages of coal to powerplants. Most of the sources had sampling devices so that the 100-pound sample obtained from each mine represented thousands of tons shipped out over a period of time.

The 11 samples were packed in plastic bags at the sampling point, placed in containers, and shipped to the Coal Preparation Laboratory at the U.S. Bureau of Mines, Pittsburgh Energy Research Center. This laboratory is isolated from the main research areas, and contamination by mercury from laboratory air was thus minimized. A sample was taken from each coal shipment and crushed to minus 60 mesh. It was then split into 20 samples of about 1 pound each. To prevent contamination from sample bottles, new plastic bottles were used; they were washed with a 2:1 mixture of concentrated HNO_3:HCl, rinsed with distilled water, then rinsed with acetone, and finally air-dried and capped.

The samples were sent to the 20 cooperating laboratories with no instructions as to how to analyze them. Thus, each laboratory employed its own techniques and reported the results to the Bureau of Mines. Accompanying many of the analyses was the analytical method used. These are described in a later section.

Many types of laboratories participated, including coal companies, power companies, State geological surveys, universities, pollution control agencies, other Government laboratories, and commercial laboratories.

TYPES OF COALS ANALYZED

The 11 coals came from a wide area; seven were Eastern Region and Appalachian coals, and four were from mines west of the Mississippi River. Besides the analyses for mercury, a sample of each coal underwent proximate and ultimate analyses by the Bureau of Mines. These determinations were of only general interest in relation to the subject study but were needed for a combustion program that is in progress to determine the distribution of trace elements in the product gas and ash from pulverized-fuel furnaces.

The Eastern coals were mostly high-volatile A bituminous coals (one was a high-volatile B bituminous coal) with free-swelling index (FSI) numbers between 5 and 8.5. Total sulfur in the coals, as received, ranged from 0.9 to 3.7 percent; two washed samples from deep mines had 0.9 and 1.3 percent sulfur. The Indiana sample was a high-volatile B coal containing 3.7 percent sulfur.

Coals from the Western mines ranged from high-volatile A to subbituminous B. They contained less than 1 percent of total sulfur except for one sample that had over 6.4 percent. This high-sulfur coal indicated no other anomalies, either in the proximate and ultimate analyses or in mercury content. These Western coals were noncaking or poorly caking. The highest free swelling index was 3.

ANALYTICAL RESULTS

Although only 14 of the 20 participating laboratories reported, the data received were sufficient to study statistically so that some suggestion may be made as to the preferred analytical methods and the extent of the mercury content of coals in selected areas. Because the coals represent a wide geographical area, some inference may also be drawn concerning the extent of mercury in coal. Discussed first is an analysis of the data, followed by detailed procedures.

The participating laboratories were requested to submit the results of individual analyses rather than averages where replicate analyses were made. In almost all cases this request was complied with.

To evaluate the submitted data, it was first necessary to obtain a value for the mercury content of the coals. As the true mercury content was unknown, an average value was used as the best approximation of the true value. This "best" value was obtained by eliminating values that differed from the average by more than two standard deviations (at the 95-percent confidence level). The averages and the standard deviations used for the comparison of values were calculated without inclusion of the values that were eliminated.

Table 1 shows the 11 coals used in the analyses, their sources, and the "best" values obtained for each. Also indicated is whether the coal was strip- or deep-mined, and if it is as-mined (raw), washed, or, as in one case, a mixture. For each best value between 22 and 37 individual determinations were used. This procedure indicated mercury contents between 0.05±0.01 and 0.41±0.06 μg of mercury per gram of coal (ppm).

Although the samples were not selected with the intent of demonstrating any geographical trend, some of the higher mercury content coals were found east of the Mississippi River and those to the west were generally lower. More extensive sampling and analysis than this limited study would be required to establish mercury distribution data. Operators concerned with potential plant emissions would require control analyses on the coal coming from a particular mine.

The methods employed in analyzing the coals could be divided into several categories. In calculating the "best" values, each set of determinations was assigned to the category representing the method of analysis and the total number of determinations in that category was used in the computations. It was felt that the best way to evaluate each method used in analyzing the coals for their mercury content was its relative success or failure in producing acceptable values. A relatively large percentage of rejected values would indicate that a particular method was inaccurate, imprecise, difficult to use in practice, or otherwise unreliable. Table 2 summarizes the results obtained when the procedure outlined above was employed.

Generally, the data could be put into four categories with the last one subdivided further for technical reasons. Except for the neutron activation procedure, all of the analytical methods used some variation of vapor phase atomic absorption as originally described by Hatch and Ott.[7] Dissolution and combustion are methods of separating mercury from the parent coal. Thereafter, the released mercury is manipulated by a series of absorption, purification, or extraction procedures.

The results of the analyses presented in table 2 show a fairly clear differentiation of the effectiveness of the methods employed to analyze the coal samples for their mercury content. Any of the methods can produce acceptable results, but some appear to have more to recommend them than others.

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[7] Hatch, W. R., and W. L. Ott. Determination of Sub-microgram Quantities of Mercury by Atomic Absorption Spectrophotometry. Anal. Chem., v. 40, Dec. 14, 1968, pp. 2085-2087.

EVALUATION OF PROCEDURES

A. Dissolution and Atomic Absorption.--The percentage of rejected values for this method is much lower than for direct combustion methods but is still fairly high. The rejections do not show a bias toward either high or low values, which indicates several potential sources of error (loss of mercury during dissolution, retention of ultraviolet absorbing species that are released with the mercury, etc.). The method is not recommended but may be used with appropriate care and a willingness to accept a fairly high percentage of inaccurate results.

B. Combustion and Atomic Absorption.--One-third of the results obtained by direct combustion methods were rejected. In addition almost all the rejected values were rejected as too high. The high results were probably due to incomplete combustion leaving aromatic hydrocarbons in the vapor stream; these compounds absorb strongly in the ultraviolet. The presence of such materials in fairly small amounts would lead to a false absorption signal at the wavelength that mercury atoms absorb and hence to an erroneously high mercury value. This method is not recommended for general use unless extreme care is taken to eliminate this major source of error.

C. Activation Analysis.--Activation analysis produced good results. Activation analysis requires the use of a nuclear reactor, expensive equipment and facilities, and experts in the field. In addition, the time required from sampling to results is relatively long and may be expensive. If none of the above considerations are objectionable, activation analysis is a recommended procedure for the analysis of mercury in coal. It should be added that activation analysis has the advantage of being able to identify and quantify a number of other elements in the same sample.

D-1. Single Silver Amalgamation and Atomic Absorption.--The single silver amalgamation method produced the same percentage of rejected values as the dissolution methods. Apparently the silver surface becomes slowly poisoned by the reactive components of the combustion gases from the coal and must be periodically discarded. This method seems to produce a bias toward low results, possibly because the mercury vapor does not all amalgamate on a partially poisoned surface and is lost. The same recommendations apply to this method as to the dissolution methods (paragraph A).

D-2. Double Gold Amalgamation and Atomic Absorption.--Double gold amalgamation followed by flameless atomic absorption probably is the method of choice for most laboratories. This method employs two gold amalgamation steps to eliminate the errors noted previously for the direct combustion method. As indicated in table 2, the double gold amalgamation and atomic absorption method appears to be accurate and precise; no values were rejected. The equipment used is fairly simple and the operator need not be an expert, although some manipulative experience is necessary to demonstrate operability of the system. A sample of coal can be analyzed for trace mercury content in less than 15 minutes with little interference. The method requires some care in the original setup, particularly when setting flow rates and heating rates, but once completed, samples can be processed on a routine basis provided the gold surface is periodically cleaned with nitric acid.

Based on these results, the Bureau constructed a double amalgamation train. The first amalgamation cell can be easily removed from the system and another inserted. This second cell would come from the sampling train on equipment being used to study the release of mercury into a gas stream.

DETAILED ANALYTICAL METHODS

As mentioned earlier, each laboratory analyzed its samples by its own preferred methods. Each approach was found to be different in some respect. Typical of the methods used were--

1. Acid digestion (dissolution) followed by flameless atomic absorption.

2. Combustion, followed by amalgamation or absorption, followed by flameless atomic absorption.

3. Neutron activation.

The nine methods described below are abstracted from those submitted by the 14 cooperating laboratories. An attempt has been made to reword the methods in a reasonably uniform format. Details of equipment size, arrangement, etc., are given when they were included in the method submitted.

Combustion-Atomic Absorption

A 0.5- to 1.0-gram sample is burned at 700° to 800° C, and the evolved gases are passed through a hot zone containing platinum metal to oxidize any organic material not completely burned in the first combustion tube. The mercury vapor is passed through a portable (Le Maire) atomic absorption unit. Mercury concentration is determined by comparison to standard samples run in the same manner. This method was reported during the mercury-in-coal study, but none of the comparative data were obtained using it.

Combustion-Acid Absorption-Atomic Absorption

Weigh 1 gram of the coal sample into a platinum boat. Introduce the sample slowly over a period of about 5 minutes into a 36-inch-long by 1-inch-OD Vycor tube furnace heated to 800° C. No visible smoke should appear between the sample and the first absorber. This time will vary from sample to sample depending on the type of coal being analyzed. Air is used for combustion and is drawn through the apparatus by a vacuum pump or water aspirator. A trap should be placed between the second absorption bottle and the pump in case the acid permanganate is accidently drawn out of the sparger.

Combustion gases are scrubbed in two 250-ml bottles connected in series and fitted with medium-fritted dip tubes. Each bottle contains 10 ml of $1\underline{N}$ $KMnO_4$ solution, 40 ml of $1\underline{N}$ H_2SO_4, and 50 ml of water. Allow the sample to combust about 10 minutes. If unburned black particles remain, stir the ash with a stainless steel spatula and return the boat to the hot portion of the tube for an additional 10 minutes.

Run a blank by sparging air through the same reagent solutions for the same length of time used for the sample. Deduct the nanograms of mercury in the blank from the nanograms in the sample before calculating the mercury content of the coal. Determination of the blank should be made close to the time for the combustion, since the mercury content of the air in one laboratory was observed to vary with the time of day. Mercury in the solutions was measured using a Beckman K-23 mercury meter.

Acid Digestion-Reduction-Atomic Absorption

Digest a 1-gram sample in 20 ml of a 15:5 H_2SO_4:HNO_3 solution. The digestion is carried out in a two-neck distilling flask fitted with a 400-mm allihn condenser. Allow acid solution to react with sample for approximately 30 minutes before applying heat. Then, gradually heat the flask until all the organic matter is destroyed, as indicated by the sample becoming straw colored. Continue boiling for 2 hours and then cool. Wash the condenser at least three times.

Mix the sample and washings with the condenser in place. Recool and transfer the sample to a 200-ml volumetric flask. Mix well and remove a 100-ml aliquot for analysis. Add 2 ml of 6 percent $KMnO_4$. Excess $KMnO_4$ should remain after 15 minutes; if not, add more 6 percent $KMnO_4$ until excess $KMnO_4$ remains 15 minutes. Next add 2 ml of saturated $K_2S_2O_8$. Wait 30 minutes and reduce the excess $KMnO_4$ with hydroxylamine hydrochloride. Reduce the mercuric ion with 2 ml $SnCl_2$. Vaporize the mercury with air flowing at about 1 liter per minute, and pass the flow through a 10-cm cell placed in the optical path of the atomic absorption analyzer. The air rate must be checked for maximum sensitivity.

Wet Ashing-Atomic Absorption

Transfer 1 gram of powdered coal to a 250-ml volumetric flask and add approximately 20 mg of $K_2Cr_2O_7$. Then add 10 ml of concentrated HNO_3 and swirl until the reaction subsides. Affix an asbestos-jacketed air condenser to the top of the flask and reflux for 30 minutes at 180° C (hotplate surface temperature). Add 15 ml of concentrated $KClO_4$ and heat for 30 minutes at 250° C; then heat at 280° C until the color of the solution turns from green to orange-red, usually 15 to 30 minutes. Allow the solution to cool to 150° C or lower and add approximately 75 ml of water and boil the solution for 10 minutes. Cool the solution to room temperature, dilute to the mark, and determine mercury as soon as possible by cold vapor atomic absorption.

Combustion-Silver Amalgamation-Atomic Absorption

In a graphite crucible place 0.2 gram of coal mixed with 0.2 gram of a 1:1 mixture of CuO:$CaCO_3$ that has been fired overnight at 750° C. Burn the sample for 5 minutes in an induction furnace with an oxygen flow of 1 liter per minute. The mercury is trapped on silver foil.

Heat the foil at 400° to 450° C to transfer the mercury vapor into the optical path of the atomic absorption spectrophotometer using a hollow cathode mercury lamp. The cell is 12 cm long by 60 mm in OD. Readout is obtained on a 10-mv strip chart recorder.

Digestion or Combustion-Amalgamation-Atomic Absorption

The sample is digested in an H_2SO_4-$HClO_4$ solution or volatilized in a quartz-graphite crucible in an induction furnace with subsequent collection in an acidic permanganate solution. The solutions are then reduced and aerated, and the mercury is amalgamated on silver foil. Mercury is then volatilized off the silver foil in an induction furnace and carried by an air stream through the quartz cell of an atomic absorption unit.

Combustion-Gold Amalgamation-Atomic Absorption

A 10- to 200-mg sample is placed in a nickel boat and burned in a laboratory furnace through which oxygen is flowing at 1.25 cu ft/hr. The vapors are passed over silver wire coils heated to 500° C to complete the oxidation. The vapors are next passed through a gold wire trap to remove mercury. To insure complete removal of contaminants that might absorb in the mercury range, the mercury is driven off the gold by heating at 600° to 700° C and reamalgamating the mercury in a second gold wire trap. The mercury is finally released from the second amalgamator by heating and passed through an 18-cm vapor cell in the optical path of the atomic absorption unit. A sharp peak is obtained on the strip chart recorder. Calibration is obtained by abstraction of mercury vapor with a syringe from a plastic bottle fitted with a septum. The contents of the syringe are passed through the entire analytical train. A second sample can be injected at the entrance of the analyzer cell to check the operation of the train. Identical peaks should be obtained.

Combustion-Dithizone

None of the samples in the series was analyzed using the dithizone method. However, this method was used in the initial series of tests with good results and is detailed here for laboratories desiring to use this procedure.

A 1.0-gram sample of coal is placed in a boat and placed in a combustion tube maintained in part at 900° C. The air rate is 400 to 500 ml per minute. The boat is initially about 4 inches from the hot zone and is advanced at a rate of 0.25 inch per minute for the first 16 inches, then 0.5 inch per minute for 16 inches. Combustion is continued for 30 minutes. The products of combustion are sparged through two absorption bottles in series, each containing 20 ml of acidified $KMnO_4$ (30 ml of H_2SO_4 in 1 liter of H_2O, then add 3.2 grams $KMnO_4$).

These solutions containing absorbed mercury are decolorized with an excess of hydroxylamine hydrochloride and transferred to a separatory funnel. Exactly 5 ml of 0.0005 percent dithizone in chloroform is added to extract the mercury. The extract is transferred to a spectrophotometer cell and the absorbance at 490 mμ is measured against chloroform. Reagent blanks are determined by adding known amounts of mercury to 40 ml of the absorbing solution, and reducing, extracting, and measuring the absorbance.

Neutron Activation

Detailed procedures for the analysis of coal by activation analysis were not submitted by any of the cooperating laboratories. However, one of the laboratories submitted data obtained in both a low-flux and a high-flux reactor. Sufficient activity could not be obtained in the low-flux system to give reliable results and so these data were not used in this study.

SOME ANALYTICAL PROBLEMS

During informal discussions with analysts who have been working on mercury analysis, several comments were made concerning pitfalls that were experienced. These are somewhat random but they may be helpful to an analyst approaching these procedures for the first time.

Mercury vapor is present in most laboratory atmospheres. Therefore, sample storage, exposure of analytical glassware, and the use of combustion air should be considered carefully.

Mercury has been lost when Teflon-coated stirring bars are used in digestion apparatus.

Complete combustion of the sample is important because aromatic compounds absorb energy at 2,536.5 A, the mercury resonance absorption wavelength. The combustion rate should be controlled so that the coal does not flash, particularly when tank oxygen is used. When the combustion is too rapid, smoke is evident in the combustion tube or the absorption bottles. Large amounts of water vapor will also affect the normally sharp peak for mercury by giving a broad absorption signal at the base of the mercury peak.

LABORATORIES INVOLVED IN THE ANALYSES

Allied Chemical Co.
American Electric Power
Bituminous Coal Research, Inc.
Consolidation Coal Co.
Detroit Edison
Illinois Geological Survey
Kennecott Copper Co.
National Bureau of Standards
Oak Ridge National Laboratories
Office of Air Programs (EPA)
Ohio Geological Survey
Pennsylvania State University
Tradet, Inc.

CONCLUSIONS

Several analytical procedures can be used for the determination of mercury in coal. The double gold amalgamation technique used by one laboratory appeared to give the most consistent results. To verify the reliability of this method, it would be advisable for other laboratories to set up a similar apparatus and to compare data. The Bureau of Mines now has such a unit in operation. Several other analytical procedures are applicable with equivalent accuracy, but care must be taken to avoid gain or loss of mercury.

Best values for the coals sampled ranged from 0.05±0.01 to 0.41±0.06 μg Hg/g of coal (ppm). The range for Eastern coals was 0.07 to 0.41, somewhat higher than that for the Western coals, which analyzed between 0.05 and 0.16 ppm. A rough average for all of the samples was about 0.14 ppm. After this study was completed, the National Bureau of Standards announced the availability of Standard Reference Material 1630 (Trace Mercury in Coal) containing 0.13 ppm mercury.

No further comparative analytical studies are indicated at this time. Instead, it is important to develop reliable techniques for the determination of other potentially hazardous elements in coal.

TABLE 1. - Determinations of arsenic in coal by three methods, percent of dry coal (1)

Source		ISO recommendation		MgO-ashing at 650° C		Dilute HNO_3 extraction	
State	County	Individual	Average	Individual	Average	Individual	Average
Alabama......	Walker...	0.0046 .0055	0.0051	0.0049 .0050	0.0050	0.0053 .0053	0.0053
Illinois.....	Stark....	.0009 .0007	.0008	.0008 .0008	.0008	.0009 .0009	.0009
Kentucky.....	Bell.....	.0004 .0003	.0004	.0003 .0003	.0003	.0004 .0003	.0004
Do.........	Butler...	.0045 .0049	.0047	.0045 .0044	.0045	.0043 .0042	.0043
Do.........	Pike.....	.0023 .0024	.0024	.0022 .0022	.0022	.0023 .0024	.0024
Pennsylvania.	Allegheny	.0032 .0027	.0030	.0030 .0029	.0030	.0031 .0032	.0032
Do.........	..do.....	.0021 .0019	.0020	.0017 .0018	.0018	.0020 .0019	.0020
Do.........	Greene...	.0018 .0016	.0017	.0017 .0019	.0018	.0021 .0021	.0021
Virginia.....	Buchanan.	.0057 .0054	.0056	.0057 .0061	.0059	.0062 .0061	.0062
Do.........	Dickenson	.0003 .0002	.0003	.0003 .0003	.0003	.0003 .0003	.0003
Do.........	Wise.....	.0012 .0012	.0012	.0013 .0014	.0014	.0016 .0016	.0016
West Virginia	Boone....	.0006 .0006	.0006	.0007 .0008	.0008	.0009 .0009	.0009
Do.........	Kanawha..	.0009 .0008	.0009	.0009 .0009	.0009	.0009 .0009	.0009
Do.........	..do.....	.0121 .0116	.0119	.0106 .0111	.0109	.0114 .0112	.0113
Do.........	..do.....	.0009 .0007	.0008	.0010 .0011	.0011	.0011 .0011	.0011
Do.........	Lewis....	.0041 .0040	.0041	.0038 .0037	.0038	.0038 .0040	.0039

(1) Abernathy, R. F. and Gibson, F. H. Bureau of Mines R.I. 7184; Oct. 1968.

PROCEDURES

ISO Recommendation No. 601

Reagents

Zinc, granular, 20 mesh.

Hydrazine sulfate solution, 0.15 percent. Dissolve 0.15 gram in 100 ml of water.

Stannous chloride solution, 40 percent. Dissolve 20 grams of $SnCl_2 \cdot 2H_2O$ in concentrated HCl and dilute to 50 ml with concentrated HCl.

Potassium iodide solution, 15 percent. Dissolve 7.5 grams of KI in 50 ml of water. Prepare fresh daily.

Lead acetate solution, saturated. Prepare fresh daily.

Sulfuric acid solution, approximately 7 N. Add 200 ml of concentrated H_2SO_4, cautiously, to about 700 ml of water, cool and dilute to 1,000 ml.

Sulfuric acid solution, 5 N. Add 140 ml of concentrated H_2SO_4, cautiously, to about 500 ml of water, cool and dilute to 1,000 ml. Standardize against sodium carbonate using methyl orange as indicator and adjust to 5.0 N.

Ammonium molybdate solution, 1 percent in 5 N H_2SO_4. Dissolve 1 gram of $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in about 80 ml of 5 N H_2SO_4 and dilute to 100 ml with the same acid.

Stock iodine solution, approximately 0.02 N. Dissolve 2.54 grams of iodine in 25 ml of water containing 8 grams of KI. Dilute to 1,000 ml and store in a dark glass bottle.

Working iodine solution, approximately 0.001 N. Dilute 5 ml of the stock iodine solution to 100 ml. Prepare fresh daily.

Stock arsenic solution (1 ml equals 1 mg As). Weigh 0.1320 gram of arsenious oxide, previously dried at 110° C for 2 hours, and dissolve in 50 ml of water containing 0.5 ml of 70 percent NaOH. Add 2 ml of the 5 N H_2SO_4 and dilute to 100 ml.

Working arsenic solution (1 ml equals 10 micrograms As). Dilute 1 ml of the stock arsenic solution to 100 ml.

Wet Oxidation Procedure

Transfer a 1-gram sample of coal, crushed to pass a No. 60 sieve, to a 300 ml Kjeldahl flask and mix with 7.0 ml of H_2SO_4. Then add 3.5 ml of HNO_3 slowly through a dropping funnel to avoid excessive frothing; after the initial reaction subsides, heat the mixture gently over a gas burner. When white fumes of SO_3 only are being evolved, add 0.2 to 0.4 ml of HNO_3 by drops into the flask. Brown fumes will be evolved for several minutes. Continue these additions of HNO_3 until all visible carbonaceous matter has been oxidized. This will require about 1-1/2 hours. After cooling, wash the walls of the flask with about 10 ml of water, add a few drops of HNO_3, and heat the solution again to complete the oxidation of organic matter. Wash the walls of the flask with water and heat the solution to fumes of SO_3, repeating the addition of water and heating to fumes of SO_3 at least once to remove the last traces of HNO_3; after the last addition of water transfer the solution and any residue to an evolution flask keeping the final volume about 35 ml.

Colorimetric Determination

Before the evolution of arsine, add 2.0 ml of the KI solution and 0.5 ml of the $SnCl_2 \cdot 2H_2O$ solution to the sample in the evolution flask, mixing after each addition. Allow the solution to stand for 15 minutes. During this time set up the evolution apparatus shown in figure 1. Add 5 ml of 0.001 N iodine solution from a pipet to the absorption tube containing the helix. Place cotton plugs in both cones of the delivery tube, moistening the larger one with lead acetate solution, and weigh out 5 grams of zinc. Add the zinc to the evolution flask and assemble the apparatus.

> Note: Some tests may give excessive evolution of hydrogen and frothing that carries over into the absorption tube. If this occurs, repeat the experiment adding about half of the zinc at first. After about 20 minutes when gas evolution has nearly ceased, add the remainder of the zinc and complete the test.

After evolution has taken place for 1 hour, disconnect the absorption tube and remove the helix. Add 0.5 ml of ammonium molybdate solution and 0.2 ml of hydrazine sulfate solution to the absorption tube from burets, closing the tube with a No. 19 glass stopper and mixing after each addition. Suspend the tube in boiling water for 10 minutes, then cool to room temperature. Transfer the blue-colored solution to a 1-cm cell and measure absorbance at 835 millimicrons, with water as reference. Carry a blank determination through the procedure.

Prepare a calibration curve using 0.0 to 1.6 ml of the standard working arsenic solution and 35 ml of 7 N H_2SO_4, carrying each test through the evolution and colorimetric procedures. Use the absorbance reading for the 0.0 arsenic solution for a blank correction. The calibration curve is nearly a straight line with the absorbance ranging from 0 to 0.87 for 0 to 16 micrograms of arsenic.

$$\text{Percent arsenic} = \frac{(a - b) \times 0.0001}{w}$$

where w = weight of sample in grams,
a = micrograms arsenic equivalent to absorbance of sample, and
b = micrograms arsenic equivalent to absorbance of blank.

> Note: If a coal contains more than 0.0016 percent arsenic, take an aliquot of the sample solution for the determination so that the amount of arsenic present is within the range of the method. When a coal with high arsenic content is found, make another determination and dilute the sample solution to 50 ml in a volumetric flask. Transfer an aliquot containing less than 16 micrograms of arsenic to an evolution flask, add 7 N H_2SO_4 to make the volume about 35 ml, and complete the determination.

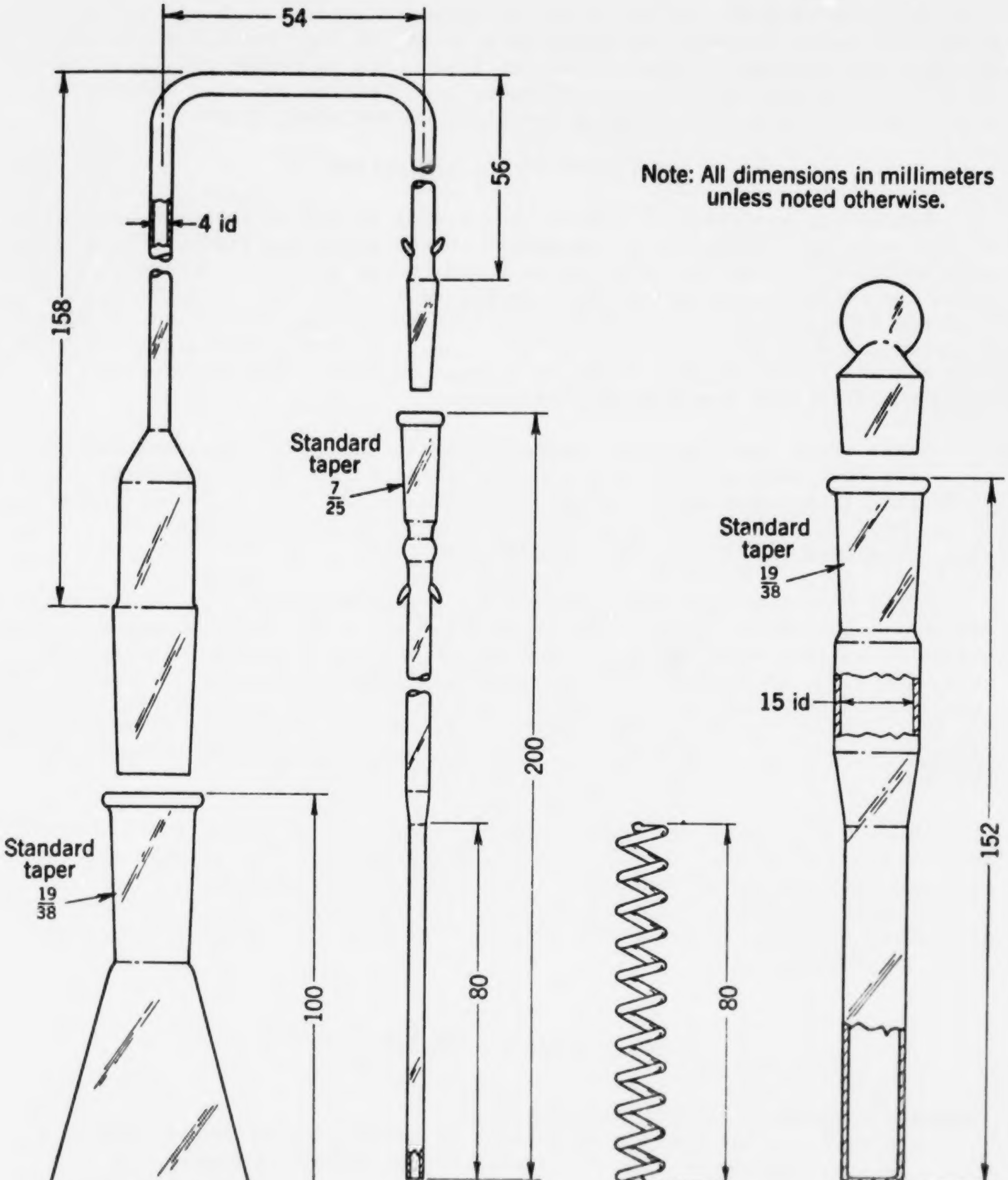
54
158
4 id
56
Note: All dimensions in millimeters unless noted otherwise.
Standard taper $\frac{7}{25}$
200
80
2 id
Standard taper $\frac{19}{38}$
100
50 ml flask
80
Standard taper $\frac{19}{38}$
15 id
152
11 id

FIGURE 1. - Evolution Apparatus.

MgO Ashing

Mix a 1-gram sample of coal in a porcelain crucible with 1 gram of MgO and moisten with 2 to 3 ml of limewater. Heat the crucible and contents slowly to 650° C in a ventilated muffle furnace and maintain this temperature for 1 hour.

After cooling, add 15 ml of 7 N H_2SO_4 to the contents of the crucible. Transfer the solution and any residue to an evolution flask, using about 20 ml of 7 N H_2SO_4. Determine arsenic by the colorimetric method.

Nitric Acid Extraction

Mix a 1-gram sample of coal in a 250-ml beaker with 50 ml of 1:7 HNO_3. Cover the beaker with a watch glass and boil the contents gently for 30 minutes. Filter the coal and acid mixture on a 9-cm filter paper and wash six times with the diluted HNO_3, collecting the filtrate in a 200-ml Erlenmeyer flask.

Add 14 ml of 1:1 H_2SO_4 to the filtrate and evaporate to fumes of SO_3. Finish the fuming by swirling the flask over the flame of a burner. After cooling, wash the walls of the flask with about 10 ml of water and evaporate to fumes again. Repeat this operation at least once to insure the removal of all the HNO_3.

Finally transfer the solution to an evolution flask, dilute with water to about 35 ml, and determine arsenic by the colorimetric method.

RESULTS

Comparison of Three Methods

Results of arsenic determinations of 16 coals by the ISO method with wet oxidation of the coal sample are given in table 1. Arsenic determinations of the same coals by the modified methods using MgO-ashing and HNO_3 extraction are included in the table for comparison. Average results by the ISO wet oxidation and the two modified methods agree within acceptable limits indicating that both the MgO-ashing and the HNO_3 extraction methods can be applied to determine arsenic in coal.

To estimate completeness of the extraction of arsenic by HNO_3 in these tests, the coal residue and filter paper were ashed in a porcelain crucible at 750° C and tested for arsenic. The ashes contained only small quantities of arsenic ranging from 0.1 to 3 micrograms. The proportion of these small amounts to the arsenic found in the acid extract indicated that the acid extraction method averaged 96 percent recovery of arsenic in the 16 coals tested.

Because several coal samples with unusually high arsenic content were used for these comparative tests, the results in table 1 are generally higher than the average arsenic content of coals from the sources shown.

Arsenic in Float- and Sink-Fractions

Mixtures of gasoline and carbon tetrachloride having specific gravities of 1.30 and 1.33, or 1.33 and 1.38, were used in float- and sink-tests of three coals. Each coal was separated into two float and two sink fractions. These fractions, with the head sample, gave five portions for each coal having a wide range of ash content. The coals were from Tennessee, West Virginia, and Pennsylvania. Arsenic was determined by the MgO-ashing method.

Yields of the float and sink fractions, and the ash and arsenic contents are given in table 2. The arsenic content decreased as the ash decreased, showing that arsenic in these coals was associated with the mineral matter. Sensitivity of the colorimetric method for determining small quantities of arsenic was demonstrated by the tests, because arsenic was not detected spectrographically in ash from the three head samples.

TABLE 2. - Arsenic in float- and sink-fractions of three coals, percent of dry coal

Specific gravity	Yield	Ash	Arsenic
MARION COUNTY, TENN.			
Float 1.33........	27.9	2.9	0.00013
Float 1.38........	69.4	5.5	.00022
Head sample.......	-	10.0	.00063
Sink 1.33.........	72.1	12.6	.00077
Sink 1.38.........	30.6	19.6	.00147
BOONE COUNTY, W. VA.			
Float 1.30........	23.1	2.0	0.00009
Float 1.33........	42.5	2.7	.00011
Head sample.......	-	14.3	.00049
Sink 1.30.........	76.9	17.5	.00057
Sink 1.33.........	57.5	22.6	.00071
WASHINGTON COUNTY, PA.			
Float 1.33........	59.9	3.9	0.00009
Float 1.38........	85.0	5.0	.00013
Head sample.......	-	9.8	.00031
Sink 1.33.........	40.1	18.8	.00058
Sink 1.38.........	15.0	36.9	.00106

High-Temperature Ashing Tests

The ISO colorimetric method was used to determine the loss of arsenic when ashes are heated to temperatures corresponding to those attained during combustion of coal in a boiler furnace. One-gram samples of coal were ashed at 750° C in porcelain capsules according to the ASTM method for determining ash content.[8] The ashes were treated with 7 N H_2SO_4 and arsenic was determined by the ISO colorimetric method. Tests were continued at higher temperatures, first preparing an ash sample at 750° C, then transferring it to a platinum capsule and heating it in a ventilated platinum wound electric furnace for 1 hour at 1,000° C. Arsenic content of the heated ash was determined; similar tests of ash samples from each coal were made at 1,100°, 1,200°, and 1,300° C.

Average results for 16 coals given in table 3 show that only a small quantity of arsenic is lost below 1,000° C. At higher temperatures an appreciable amount of it is volatilized; virtually all of it is removed at 1,300° C. Although the tests indicate that most of the arsenic in coal is volatilized during combustion, it is probable that, because of the high temperature required, some arsenic may remain in the cooler parts of the furnace and not escape with the flue gas.

TABLE 3. - Arsenic remaining after heating coal ash at various temperatures, percent of dry coal

Source		Total arsenic in coal[1]	Arsenic found after heating at various temperatures				
State	County		750° C	1,000° C	1,100° C	1,200° C	1,300° C
Alabama......	Walker...	0.0051	0.0043	0.0044	0.0014	0.00[illegible]	<0.0001
Illinois.....	Stark....	.0008	.0007	.0007	.0007	.00[illegible]	<.0001
Kentucky.....	Bell.....	.0004	.0003	.0003	.0001	<.0001	.0000
Do.........	Butler...	.0045	.0042	.0037	.0010	<.0001	.0000
Do.........	Pike.....	.0023	.0022	.0021	.0019	.0003	<.0001
Pennsylvania.	Allegheny	.0031	.0028	.0027	.0023	.0002	<.0001
Do.........	..do.....	.0019	.0016	.0018	.0017	.0006	.0000
Do.........	Greene...	.0019	.0017	.0019	.0019	.0003	.0000
Virginia.....	Buchanan.	.0059	.0055	.0054	.0020	.0004	.0000
Do.........	Dickenson	.0003	.0003	.0003	.0003	.0003	.0000
Do.........	Wise.....	.0014	.0013	.0013	.0006	<.0001	.0000
West Virginia	Boone....	.0008	.0008	.0008	.0008	.0001	.0000
Do.........	Kanawha..	.0009	.0008	.0008	.0006	.0002	.0000
Do.........	..do.....	.0114	.0105	.0083	.0021	.0001	.0000
Do.........	..do.....	.0010	.0010	.0010	.0010	<.0001	.0000
Do.........	Lewis....	.0039	.0035	.0036	.0035	.0004	.0000

[1] Average by 3 methods from table 1.

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[8] American Society for Testing and Materials. Standard Methods of Laboratory Sampling and Analysis of Coal and Coke. D 271-64 in 1968 Book of ASTM Standards: Part 19, Gaseous Fuels; Coal and Coke. Philadelphia, Pa., 1968, pp. 22-23.

CONCLUSIONS

1. ISO Recommendation No. 601 for determination of arsenic in coal gives satisfactory results.

2. A modification, using furnace ashing of the coal sample mixed with MgO, requires less manipulation and gives results similar to those obtained by the ISO wet oxidation method.

3. A second modification, in which the arsenic is extracted from the coal sample with hot dilute HNO_3 without ashing, also gives satisfactory results for arsenic.

4. Determinations of arsenic in float- and sink-fractions of coal indicate that the arsenic is associated mainly with mineral matter in the three coals tested.

5. High-temperature ashing tests show that very little arsenic is lost up to 1,000° C, but virtually all of it is removed from the ash at 1,300° C.

COLORIMETRIC DETERMINATION OF BERYLLIUM IN COAL*

by

Roy F. Abernethy[1] and Elizabeth A. Hattman[2]

ABSTRACT

This report describes a method developed by the Bureau of Mines for the determination of beryllium in coal ash. Samples are put into solution by standard wet chemical procedures. Interfering elements are complexed with Na_2EDTA, and the beryllium is separated by extraction of its acetyl acetone complex with chloroform or carbon tetrachloride. Final determination is made with Beryllon II.

INTRODUCTION

Although coal contains only trace amounts of beryllium, air pollution from this very toxic element is a possibility in areas where large amounts of coal are burned. A spectrographic survey of trace elements in the ash from U.S. commercial coals detected beryllium in all coals tested.[3] The approximate lower limit of detection was 0.0001 percent beryllium, reported as the metal. Some samples contained as much as 0.02 percent beryllium but the average values for the three provinces were 0.0012 for the Eastern Province, 0.0014 for the Interior Province, and 0.0006 for the Western Province.

Spectrometry is most often used to determine trace quantities of beryllium. However, an accurate chemical method is desirable since small laboratories may not have access to spectrographic equipment. Such a method could also serve as an independent check.

Several spectrophotometric methods have sufficient sensitivity for the determination of the microgram quantities of beryllium present in coal ash. The procedure using morin is the most sensitive but requires a fluorphotometer.

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[1] Former project coordinator, Pittsburgh Energy Research Center, Bureau of Mines, Pittsburgh, Pa. (now retired).

[2] Research chemist, Pittsburgh Energy Research Center, Bureau of Mines, Pittsburgh, Pa.

[3] Abernethy, R. F., M. J. Peterson, and F. H. Gibson. Spectrochemical Analyses of Coal Ash for Trace Elements. BuMines Rept. of Inv. 7281, 1969, 30 pp.

* Bureau of Mines, RI 7452; Nov. 1970.

Procedures have been developed by McCloskey[4] and by Crawley[5] which use Aluminon as the colorimetric reagent.

Acetyl acetone has been used both for the isolation of beryllium and for its final determination. Adam, Booth, and Strickland[6] determined beryllium by first isolating it with an acetyl acetone-chloroform extraction; destroying the complex by wet oxidation; and reextracting the acetyl acetone complex. Since the absorbance of the beryllium acetonate-chloroform solution is strongest at 295 mμ, an ultraviolet spectrophotometer must be used.

Others[7] also isolated beryllium with acetyl acetone but used the reagent Beryllon II for the final determination. The sensitivity of this method is good and the beryllium-Beryllon II complex is stable; however, the complex does not follow Beer's law. The Bureau of Mines selected this two-step procedure for trial as a method for the determination of beryllium in coal ash.

EXPERIMENTAL WORK

Description of Method

Reagents

Standard beryllium solution (1 ml = 2.0 μg Be). Dissolve 0.1965 g $BeSO_4 \cdot 4H_2O$ in 25 ml HCl. Dilute to 1 liter and mix. Transfer 200 ml to a 1-liter volumetric flask. Dilute to the mark with 0.1 percent HCl and mix. Store in a plastic bottle.

Na_2EDTA solution, 10 percent aqueous. Adjust to a pH of 6.0 with 10 percent NaOH solution.

Sodium hydroxide solution, 10 percent aqueous.

Beryllon II solution, 0.1 percent aqueous. Make fresh weekly.

Acetyl acetone solution, 5 percent aqueous.

Preparation of Calibration Curve

Aliquot 2-, 4-, 6-, and 8-μg quantities of standard beryllium solution into 50-ml beakers. Dilute to about 15 ml and add 2 ml of 10 percent Na_2EDTA.

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[4] McCloskey, J. P. Specific Spectrophotometric Microdetermination of Beryllium. Microchemical J., v. 12, 1967, pp. 32-39.

[5] Crawley, R. H. A. Spectrophotometry of Beryllium. Anal. Chim. Acta, v. 22, 1960, pp. 413-442.

[6] Adam, J. A., E. Booth, and J. D. H. Strickland. The Determination of Microgram Amounts of Beryllium Using Acetyl Acetone. Anal. Chim. Acta, v. 6, 1952, pp. 462-471.

[7] Dushina, J. K. (Spectrophotometric Determination of Beryllium in Rocks With Beryllon II.) Vop. Prikl. Geochim., No. 1, 1966, pp. 125-128.
Rubtsov, A. F. (Isolation and Determination of Beryllium in the Study of Corpses.) Sb. Tr. po Sudebn. Med. i Sudebn. Khim., Perm, 1961, pp. 236-240.

Adjust the pH of the solution to 12.05 ±0.05 using 10 percent NaOH. Since this value is very critical, a pH meter should be used. Add 1 ml of Beryllon II solution, transfer to a 25-ml volumetric flask, and dilute to the mark using water which has been adjusted to a pH of 12.05. Prepare a blank using water, and 2 ml of 10 percent Na_2EDTA. Adjust the pH to 12.05 ±0.05, transfer to a 25-ml volumetric flask and dilute to the mark. After 5 minutes measure the absorbancies of the standards at 625 mμ, using the blank solution as a reference. The complex is stable for at least 4 hours but does not obey Beer's law.

Preparation of Ash

Spread 100 g of the coal, ground to pass a No. 60 sieve, in a fire clay roasting dish. Place in a cold muffle furnace equipped with an air aspirator, and heat to 500° C. After 1 hour raise the temperature to 750° C. Ignite until most of the carbon is burned off. Transfer the ash to a silica dish and continue heating until the weight is constant. Grind the ash in an agate mortar to pass through a No. 100 sieve.

Procedure

Weigh a 0.500-g sample of coal ash, transfer to a 100-ml beaker, and digest with 10 ml concentrated HCl for 10 to 15 minutes. Add 10 ml of water and filter through a retentive paper into a 250-ml beaker. Wash the paper and precipitate several times with hot water. Reserve the filtrate and ignite the filter paper and precipitate in a platinum crucible in a muffle furnace at 750° C. When the carbon has been burned off, cool the crucible and contents and add 1 or 2 ml of water, 5 drops of 1:1 H_2SO_4, and 2 to 3 ml of HF. Fume to dryness and fuse the residue in 3 to 5 g of potassium pyrosulfate. Cool, and place crucible and lid in the reserved filtrate. Heat, and when the melt is dissolved, remove and rinse the crucible and lid. Add 4 g Na_2EDTA, adjust the pH to approximately 6 with 10 percent NaOH, and boil until the $Fe(OH)_3$ precipitate dissolves and the volume of the solution is about 60 ml. Adjust the pH to 6.0 ±0.1 and boil again if a precipitate forms. Cool, add 5 ml of 5 percent acetyl acetone solution, and let stand for 5 minutes. Transfer to a 125-ml separatory funnel and extract three times with 25-ml, 10-ml, and 5-ml portions of CCl_4, collecting the CCl_4 layers in a 100-ml beaker. To the combined extracts add 10 ml concentrated HNO_3 and evaporate to dryness. Add 2 drops concentrated HCl and 10 ml water, and heat to dissolve the residue. Cool, transfer to a 25-ml volumetric flask and adjust to volume. Pipet a 10-ml aliquot into a 50-ml beaker, dilute to 15 ml, and add 2 ml of 10 percent Na_2EDTA. Adjust the pH of the solution to 12.05 ±0.05 using a pH meter. Add 1 ml of Beryllon II solution, transfer to a 25-ml volumetric flask, and dilute to the mark using water which has been adjusted to a pH of 12.05. Prepare a blank using water and 2 ml of 10 percent Na_2EDTA. Adjust the pH to 12.05 ±0.05, transfer to a 25-ml volumetric flask, and dilute to the mark. After 5 minutes measure the absorbance at 625 mμ, using the blank solution as a reference.

The sample weight and aliquot specified is suitable for ash samples containing up to 0.0020 percent beryllium. Smaller aliquots can extend the range.

When the sample is known to contain less than 0.0010 percent beryllium, the entire solution of the residue can be used for color development, omitting the use of an aliquot. The optimum concentration for color development is from 1 to 6 µg of beryllium in the final 25-ml volume.

Effect of pH on Absorbance

The influence of pH on the intensity of the beryllium-Beryllon II complex was investigated. As shown in table 1, the pH range for maximum color development is very narrow. Solutions which have pH values between 12.0 and 12.1 have the highest absorbancies. Since this value is very critical, a pH meter should be used for adjustment.

TABLE 1. - Effect of pH on absorbance

pH	Absorbance[1]	pH	Absorbance[1]
11.70	0.290	12.05	0.325
11.80	.305	12.10	.325
11.85	.311	12.15	.323
11.90	.318	12.20	.317
11.95	.322	12.30	.310
12.00	.324		

[1] Absorbance measurements made at 625 mµ, using 1-cm cuvettes, with a beryllium concentration of 6 µg/25 ml.

Recovery of Beryllium

In initial tests two separations were used to free the beryllium from interfering ions. Various amounts of beryllium were added to base solutions containing 250 mg of aluminum oxide and 140 mg of ferric oxide. Interfering ions were complexed with Na_2EDTA. The pH was adjusted to 6.0, acetyl acetone was added, and the solution was extracted with carbon tetrachloride. Nitric acid was added, and the extract was evaporated to dryness. The residue was dissolved in hydrochloric acid, diluted, and extracted as before. After evaporation of the organic layer, beryllium was determined using Beryllon II.

Since this procedure using two extraction steps was time consuming, tests were made to determine if a single extraction would suffice. Synthetic ash samples containing 400 mg of aluminum oxide, 140 mg of ferric oxide, and varying amounts of beryllium were tested. Table 2 shows satisfactory recoveries for both procedures. This table also shows the sensitivity of the method since as little as 0.5 µg of beryllium can be recovered.

Beryllium was determined on several coal ashes, using both single and double separations to isolate the beryllium. As table 3 indicates, the results show no significant difference and the use of a double separation appears unnecessary.

TABLE 2. - Recoveries of beryllium from base solutions

Beryllium added, μg	Double separation		Single separation	
	Beryllium found, μg	Recovery, percent	Beryllium found, μg	Recovery, percent
0.5	-	-	0.4	80
.5	-	-	.5	100
2	2.0	100	-	-
2	2.1	105	-	-
6	5.7	95	-	-
6	6.3	105	-	-
8	7.3	91	-	-
8	7.7	96	-	-
10	10.0	100	10.0	100
10	9.8	98	9.8	98
10	-	-	10.1	101
20	20.5	103	-	-
30	30.0	100	30.3	101
30	28.5	95	31.0	103
30	-	-	30.0	100
40	-	-	40.0	100
40	-	-	40.0	100
40	-	-	40.0	100

TABLE 3. - Comparison of results for beryllium in coal ash using single and double separations

Sample number	Beryllium, percent of ash	
	Single separation	Double separation
1	0.0014	
	.0013	
	.0013	
	.0013 (avg)	0.0015
2	.0072	
	.0073	
	.0073	
	.0073 (avg)	.0076
3	.0083	
	.0081	
	.0082 (avg)	.0082
4	.0055	
	.0053	
	.0054 (avg)	.0054
5	.0068	
	.0068	
	.0068 (avg)	.0067
6	.0094	
	.0094	
	.0094 (avg)	.0095

Reproducibility of Method

Ten replicate determinations were made on each of two coal ash samples to obtain data on precision. The first sample averaged 0.0082 percent beryllium and showed a relative standard deviation of 3.7 percent. On the second ash, averaging 0.0178 percent beryllium, the relative standard deviation was 2.2 percent.

For comparison, beryllium was determined by atomic absorption spectrophotometry on two of the coal ash samples. These results are given below:

Source	Atomic absorption	Beryllon II
Fulton County, Ill......	0.0015	0.0015
Do..............	.0014	.0015
Average...........	.0015	.0015
Greene County, Ind......	.0075	.0083
Do..............	.0076	.0081
Average...........	.0076	.0082

Interferences

The extraction of the beryllium acetyl acetone complex in the presence of Na_2EDTA eliminates virtually all interferences in the determination. Coextraction of iron and aluminum could cause a positive error in the beryllium determination. When 0.2 mg of aluminum was added to 6 μg of beryllium, the relative error was 2.5 percent. Similarly, 0.5 mg of iron caused a relative error of 1.7 percent. However, analysis of the extract of a 0.5-g ash sample containing 28 percent aluminum oxide showed that less than 0.1 mg of aluminum was carried over with the beryllium. Determination of iron on the extract from a 0.5-g sample containing 25 percent ferric oxide showed less than 0.1 mg of iron in the extract. These amounts would not interfere with the determination.

It was found that alkali salts enhance the intensity of the beryllium-Beryllon II complex. Therefore, the concentration of salts in both standards and sample must be constant. Readings obtained when beryllium was added to the extracts from synthetic ash solutions were no higher than those for standards run directly. This indicates no appreciable carryover of salts.

To investigate the possibility of loss of beryllium in the ashing process, samples of a high-beryllium coal were ignited in an oxygen bomb. The beryllium contents of these samples were not significantly higher than those obtained on the 750° C ash from the muffle furnace.

BERYLLIUM DETERMINATION ON THE ASH OF U.S. COALS

Beryllium was determined on the ash of 34 coals by the procedure previously described. The percent of ash in the coals ranged from 1.9 to 31.7; and these ashes contained 0.0005 to 0.020 percent beryllium. Duplicate determinations agreed very well, and the varied composition of the ashes caused no difficulty. The results of these determinations are given in table 4.

TABLE 4. - Beryllium in ash of U.S. coals

State and county	Bed	Ash, percent of air-dried coal	Beryllium, percent of ash		
			Test 1	Test 2	Average
Alabama:					
Walker..........	Cobb..................	10.9	0.0018	0.0018	0.0018
Do............	Black Creek..........	1.7	.0048	.0048	.0048
Colorado:					
Fremont.........	Unknown..............	16.7	.0013	.0013	.0013
Do............	..do.................	9.5	.0016	.0016	.0016
Moffat..........	..do.................	3.0	.0005	.0004	.0005
Illinois:					
Fulton..........	No. 5................	11.6	.0015	.0015	.0015
Logan...........	..do.................	16.8	.0010	.0010	.0010
Peoria..........	No. 6................	8.1	.0030	.0030	.0030
Indiana:					
Clay............	Upper Brazil Block...	4.3	.0067	.0069	.0068
Greene..........	No. 4................	7.8	.0081	.0083	.0082
Sullivan........	No. 5................	11.1	.0025	.0025	.0025
Vigo............	..do.................	25.5	.0009	.0009	.0009
Warrick.........	..do.................	12.4	.0016	.0016	.0016
Kentucky:					
Floyd...........	Elkhorn No. 3........	5.7	.0056	.0058	.0057
Hopkins.........	No. 6................	1.9	.0203	.0205	.0204
Do............	..do.................	4.1	.0077	.0074	.0076
Letcher.........	Elkhorn No. 3........	6.2	.0036	.0036	.0036
Ohio............	No. 9................	17.2	.0009	.0009	.0009
Ohio:					
Coshocton.......	Middle Kittanning....	5.9	.0038	.0040	.0039
Do............	..do.................	7.8	.0012	.0012	.0012
Belmont.........	Pittsburgh...........	15.4	.0008	.0008	.0008
Perry...........	..do.................	12.6	.0051	.0057	.0054
Pennsylvania:					
Lawrence........	Lower Kittanning.....	5.4	.0074	.0072	.0073
Virginia:					
Buchanan........	Lower Banner.........	14.3	.0010	.0010	.0010
Montgomery......	Brushy Mountain......	31.7	.0006	.0006	.0006
Wise............	Taggart..............	1.7	.0060	.0063	.0062
West Virginia:					
Boone...........	Winifrede............	7.7	.0067	.0068	.0068
Fayette.........	Coalburg.............	7.3	.0009	.0009	.0009
Harrison........	Pittsburgh...........	13.1	.0009	.0009	.0009
Kanawha.........	Campbell Creek.......	4.5	.0051	.0053	.0052
Do............	Eagle A..............	3.6	.0183	.0175	.0177
Do............	Peerless.............	3.2	.0033	.0037	.0035
Logan...........	Chilton..............	5.0	.0115	.0121	.0118
Preston.........	Upper Freeport.......	22.6	.0008	.0008	.0008

BERYLLIUM IN FLOAT AND SINK FRACTIONS

Float and sink tests were made on three coals, and beryllium was determined on the ash of the various fractions. A mixture of benzene and carbon tetrachloride was used to provide a liquid having a specific gravity of 1.35, and carbon tetrachloride alone was used for the 1.58 specific gravity liquid. As table 5 shows, the beryllium content of the coal increased as the percent of ash decreased, indicating that the beryllium is mainly associated with the organic fraction of the coal.

TABLE 5. - Beryllium in float and sink fractions of three coals

	Yield	Ash, percent	Beryllium in ash, percent	Beryllium in coal, percent
Float at 1.35..........	65.1	3.6	0.0188	0.00068
Float at 1.58..........	97.8	6.4	.0098	.00063
Whole coal.............	-	7.6	.0082	.00062
Sink at 1.35...........	34.9	15.0	.0037	.00056
Sink at 1.58...........	2.2	51.4	.0007	.00036
Float at 1.35..........	86.8	1.7	.0400	.00068
Whole coal.............	-	3.6	.0178	.00064
Sink at 1.35...........	13.2	17.0	.0036	.00061
Float at 1.35..........	22.6	3.4	.0063	.00021
Float at 1.58..........	89.9	8.5	.0023	.00020
Whole coal.............	-	11.8	.0016	.00019
Sink at 1.35...........	77.4	14.7	.0012	.00018
Sink at 1.58...........	10.1	41.6	.0003	.00013

CONCLUSIONS

1. The described method is suitable for the determination of beryllium in coal ash, and only usual analytical equipment is needed.

2. Beryllium can be separated from interfering ions by a single extraction of its acetyl acetone complex.

3. Tests of float and sink fractions of three coals showed that in these coals the beryllium was associated with the organic fraction.

Chemical analysis for germanium and gallium in head samples of fly ash and flue dust*

Source	Type of firing	Analysis, pct	
		Ge	Ga
Peoria, Ill., powerplant	Stoker-fired	0.053	0.010
Do	do	.025	.006
Do	Pulverized fuel	.008	.003
University of Missouri at Rolla (stack hopper).	Chain grate	.050	.017
Do	do	.022	.005
Do	do	.039	.003
University of Missouri at Rolla (boiler hopper).	do	.018	.004
Springfield powerplant (cyclone collector hopper).	Pulverized fuel	.003	.003
Do	do	.002	.002
Do	Cyclone-fired	.003	.004
Phosphorus furnace, Monsanto, Tenn. (precipitator).	Electric furnace	.010	.021
Do	do	.015	.069
Do	do	.007	.015

Chemical analysis of phosphorus furnace flue dust*

Material	Percent	Material	Percent
SiO_2	25.13	SO_3	1.00
K_2O	19.28	Fe_2O_3	.97
P_2O_5	18.89	MgO	.73
CaO	9.51	Cl	.72
C	8.81	Moisture (free)	.50
Al_2O_3	4.06	MnO	.28
F	3.78	PbO	.25
Na_2O	2.09	Total[1]	96.00

[1] Carbonates, combined water, and volatile organic matter could easily account for the remaining 4 percent.

* Waters, R. F. and Kenworthy, H., Bureau of Mines, RI 6940; April, 1967.

SPECTROCHEMICAL ANALYSIS OF COAL ASH*

Comparison of spectrochemical values with results from other methods

Sample	Method[1]	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	SO_3
1..........	OES	44	25	24	1.2	0.6	1.4	-	-	[2]0.6
	WC	42.4	27.4	23.1	1.3	.8	1.5	.6	1.8	.7
	AA	-	-	-	1.1	.5	-	.4	2.0	-
	XRS	50.4	30.5	23.5	1.3	-	1.6	-	-	-
2..........	OES	40	22	24	2.7	.8	.9	-	-	[2]2.6
	WC	39.8	26.2	23.0	3.2	.8	1.0	.8	1.8	2.8
	AA	-	-	-	2.9	.8	-	.5	1.8	-
	XRS	47.5	28.3	24.0	2.8	-	1.0	-	-	-
3..........	OES	33	16	9.2	22	5.5	.7	-	-	[2]13.2
	WC	31.3	12.8	9.4	20.8	5.0	.7	5.4	.4	13.7
	AA	-	-	-	20.1	4.6	-	5.2	.4	-
	XRS	32.2	13.5	11.0	20.7	-	.7	-	-	-
4.........	OES	46	31	20	1.3	0.5	1.1	-	-	[2].9
	WC	42.4	33.9	18.8	1.4	.4	1.0	.5	.9	.9
	AA	-	-	-	1.2	.4	-	.6	.9	-
	XRS	42.8	33.2	18.5	1.4	-	1.3	-	-	-
5.........	OES	35	20	32	3.1	.9	.8	-	-	[2]3.4
	WC	36.1	21.9	31.1	3.2	1.0	.9	.7	1.1	3.4
	AA	-	-	-	2.9	.9	-	.4	1.0	-
	XRS	37.0	22.5	33.8	2.8	-	.9	-	-	-
6.........	OES	43	20	5.1	13	2.8	1.0	-	-	[2]11.2
	WC	39.3	19.5	4.7	12.4	3.0	.7	7.8	.8	10.8
	AA	-	-	-	12.1	2.4	-	7.3	.8	-
	XRS	42.8	20.0	5.4	13.2	-	.9	-	-	-
7.........	OES	42	18	37	2.7	.5	.8	-	-	[2]1.4
	WC	40.3	[3]20.0	33.7	2.2	.5	-	.3	1.1	1.3
	AA	-	-	-	2.4	.5	-	.4	1.1	-
	XRS	42.0	19.5	36.0	2.4	-	.9	-	-	-
8.........	OES	43	19	28	4.0	.7	.9	-	-	[2]2.3
	WC	42.0	[3]22.0	26.2	4.1	.9	-	.5	1.5	2.3
	AA	-	-	-	3.9	.7	-	.5	1.4	-
	XRS	45.8	21.5	28.3	4.1	-	.7	-	-	-
9.........	OES	58	14	5.6	6.9	1.1	.8	-	-	[2]8.5
	WC	60.1	14.3	5.2	7.0	1.3	.7	1.2	1.5	8.2
	AA	-	-	-	6.4	1.1	-	1.2	1.4	-
	XRS	68.0	15.5	6.5	7.2	-	.8	-	-	-
10.........	OES	54	22	4.0	9.8	2.4	.9	-	-	[2]7.1
	WC	51.8	23.1	3.3	9.9	2.2	.7	.7	.6	6.8
	AA	-	-	-	9.9	2.1	-	.7	.7	-
	XRS	57.0	26.0	4.0	11.0	-	.9	-	-	-

* Zink, J. B., et al Bureau of Mines, RI 6985; July, 1967.

11.........	OES	43	17	11	13	2.8	1.1	-	-	[2]14
	WC	39.7	18.2	10.9	13.2	2.3	.9	.5	.1	13.1
	AA	-	-	-	12.3	2.3	-	.6	.1	-
	XRS	44.0	20.0	12.6	14.0	-	1.0	-	-	-
12.........	OES	40	21	19	5.9	1.0	.9	-	-	[2]4.5
	WC	40.7	24.0	18.5	5.8	1.2	.7	1.3	1.4	4.6
	AA	-	-	-	5.4	1.1	-	1.2	1.3	-
	XRS	42.2	25.4	20.5	6.0	-	1.0	-		-

[1] OES--optical emission spectrochemical.
WC--wet chemical.
AA--atomic absorption spectrometric.
XRS--X-ray spectrometric.

[2] Determined by a combustion method.

[3] Includes TiO_2 and P_2O_5 that may be present.

METHOD FOR DETERMINATION OF FLUORINE IN COAL[*]

By R. F. Abernethy and F. H. Gibson

TABLE 6. - Fluorine, phosphorus, and ash content of U.S. coals, percent of dry coal

State and county	Bed	Phosphorus	Ash	Fluorine	Laboratory number
Alabama:					
Jefferson	Mary Lee	0.021	11.7	0.010	H12330
Walker	Cobb	.006	11.0	.007	H12657
Colorado:					
Las Animas	-	.111	9.2	.012	G37545
Mesa	-	.025	13.2	.010	G27534
Illinois:					
Sangamon	No. 5	.015	16.3	.007	G18167
Stark	No. 6	.006	8.9	.007	G90361
Williamson	Davis & DeKoven	.013	11.2	.012	G89597
Indiana: Pike	No. V	.007	9.1	.005	G28991
Iowa: Marion	-	.039	16.0	.012	G93238
Kentucky:					
Bell	Mason	.001	2.2	.003	H12379
Hopkins	No. 9	.008	7.9	.010	G38995
Do	No. 12	.009	15.6	.011	G40652
Muhlenberg	do	.024	11.5	.008	G88941
Webster	No. 14	.005	9.0	.006	G32933
Missouri:					
Henry	Tebo	.007	11.8	.008	G91907
Macon	Bevier	.001	10.1	.005	G92316
Montana:					
Dawson	-	.058	19.3	.007	G41359
Garfield	-	.004	16.8	.006	G99643
Park	-	.024	7.2	.007	H170
Do	-	.001	13.6	.006	H171
Ohio:					
Belmont	Pittsburgh	.007	10.8	.007	G85000
Do	Sewickley	.004	11.3	.007	G83233
Jefferson	Middle Kittanning	.034	8.6	.011	G73855
Do	Pittsburgh	.018	15.0	.012	G73931
Do	do	.012	11.5	.008	G73404
Do	do	.008	10.4	.006	G76188
Perry	Lower Kittanning	.029	12.9	.006	G57464

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[*] U.S. Bureau of Mines, RI 7054 (1967).

TABLE 6. - Fluorine, phosphorus, and ash content of U.S. coals, percent of dry coal--Continued

State and county	Bed	Phosphorus	Ash	Fluorine	Laboratory number
Pennsylvania:					
Butler	Upper Freeport	0.029	12.4	0.007	G34907
Greene	Pittsburgh	.003	9.1	.003	H6814
Indiana	Upper Freeport	.038	8.2	.010	G36005
Jefferson	Lower Kittanning	.097	7.6	.019	G96138
Lawrence	Brookville	.055	10.3	.014	G42749
Mercer	do	.015	5.7	.006	G41526
Washington	Pittsburgh	.010	9.8	.006	H9707
Westmoreland	do	.005	8.1	.004	H12540
Tennessee:					
Anderson	Dean	.026	16.5	.011	H10935
Claiborne	Jellico	.017	5.2	.005	H10541
Grundy	Sewanee	.047	9.6	.013	H12001
Do	Upper Sewanee	.069	9.7	.015	G47455
Marion	Sewanee	.068	10.0	.011	H11585
Sequatchie	do	.092	11.8	.017	H11590
Utah: Emery		.023	9.6	.008	G33242
Virginia:					
Buchanan	Hagy	.006	5.5	.003	G47547
Do	Kennedy	.005	7.7	.006	G50488
Do	Splash Dam	.014	5.7	.005	G51231
Do	do	.008	5.3	.004	G51232
Do	do	.004	6.3	.005	H1003
Dickinson	Lower Banner	.005	6.3	.004	G46967
Wise	Imboden	.017	8.3	.006	H1874
Washington:					
King	Black Knight	.069	9.5	.009	G92979
Do	do	.018	22.4	.016	G92980
Pierce	Wilkinson	.052	12.4	.007	G20856
Do	Wilkinson No. 3	.078	11.2	.009	G49862
Do	Wilkinson No. 8	.092	14.2	.011	G49863
Do	Wilkinson No. 7	.066	6.1	.006	G49864
Do	Wilkinson No. 11	.148	13.0	.010	G49865
West Virginia:					
Barbour	Pittsburgh	.014	8.8	.005	G97165
Do	Redstone	.054	7.1	.010	G97164
Do	Upper Freeport	.077	16.2	.007	G94024
Do	Upper Kittanning	.020	14.2	.010	G94787
Boone	Coalburg	.032	14.3	.014	G82905
Harrison	Pittsburgh	.043	10.2	.007	G72941
Do	do	.017	9.2	.006	G66082
Do	do	.010	9.9	.005	G64667
Do	do	.002	7.8	.004	G70425
Do	Redstone	.041	7.4	.010	G75317
Do	do	.009	5.9	.005	G73969

TABLE 6. - Fluorine, phosphorus, and ash content of U.S. coals, percent of dry coal--Continued

State and county	Bed	Phosphorus	Ash	Fluorine	Laboratory number
West Virginia--Con:					
Kanawha..........	Campbell Creek........	0.059	4.5	0.012	H212
Do............	Cedar Grove..........	.001	4.5	.001	G71933
Do............	..........do..........	.003	5.3	.003	G71118
Do............	Stockton-Lewiston.....	.064	8.1	.011	G71117
Lewis...........	Pittsburgh............	.022	9.2	.006	H5634
Mingo...........	Campbell Creek........	.011	5.7	.004	G73437
Do............	Eagle................	.002	4.3	.002	G45812
Monongalia.......	Redstone.............	.039	11.0	.015	G27569
Do............	Upper Kittanning......	.003	9.8	.005	G29432
Nicholas.........	Campbell Creek........	.034	4.9	.008	H301
Do............	..........do..........	.016	3.3	.004	G99354
Pocahontas.......	Sewell...............	.023	4.9	.004	G98810
Preston..........	Bakerstown...........	.004	8.0	.002	G24779
Do............	Lower Kittanning......	.034	9.5	.009	G26543
Do............	Upper Freeport........	.041	22.6	.019	G57099
Wyoming: Carbon...	-	.032	14.4	.007	H22

SULFUR CONTENT OF UNITED STATES COALS*

by

Joseph A. DeCarlo,[1] Eugene T. Sheridan,[2]
and Zane E. Murphy[3]

INTRODUCTION

Coal is one of our basic sources of energy (heat, power, light) and an essential raw material for most metallurgical processing. More than two-thirds of the electricity currently produced by thermal powerplants in the United States is generated by coal, and it is expected that coal will continue to be the major fuel used for this application at least through the 1970's. Coke produced from bituminous coking coal is the principal fuel of iron blast furnaces, and unless ironmaking methods change greatly, coal will continue to maintain a dominant role in iron-ore processing and steel manufacturing for many years. Export markets are expected to increase also, adding to the over-all increased demand for coal. Accompanying the increased total requirement, however, will be an ever-increasing demand for higher quality coals, specifically, coals of low sulfur content.

RESERVES

The United States is fortunate in having tremendous reserves of coal. In terms of energy equivalents, known recoverable reserves of coal comprise over 83 percent of the total for all fossil fuels (petroleum, natural gas, natural-gas liquids, oil in bituminous rock, and shale oil). Remaining reserves of coal of all ranks as of January 1, 1965, are estimated at 1,576,167 million tons, based on U.S. Geological Survey data, and are shown in table A-1. Approximately two-thirds of the estimated reserve may be considered low-sulfur coals largely because more than one-half of the total is composed of low-rank coals (subbituminous and lignite) which generally contain 1 percent or less sulfur. Most of these reserves are in areas in the Western United States which are not highly industrialized, and original reserves of these coals, unlike those in the East, remain virtually intact.

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[1] Supervisory chemical engineer.
[2] Mineral specialist.
[3] Chemical engineer.
All authors are with the Division of Bituminous Coal, Bureau of Mines, Washington, D. C.

Work on manuscript completed May 1966.

* Bureau of Mines, IC 8312 (1966).

The estimated original coal reserves, and estimated remaining reserves on January 1, 1965, by rank, in various States are depicted graphically in figure 1. The estimated relative proportions of high-, medium-, and low-sulfur coals of all ranks remaining in the United States on January 1, 1965, are shown in figure 2. Estimated remaining coal reserves, by rank and sulfur level, for States east of the Mississippi River, are shown in figure 3.

PRODUCTION

The quantity of coals produced in the United States in 1964, according to rank and sulfur content, are summarized in tables A-2 and A-3 and figures 4, 5, and 6. These data show that approximately 96 percent of the total output of all ranks was bituminous (including subbituminous) coal, 3 percent was anthracite, and less than 1 percent was lignite. The lignitic coals generally are low in sulfur, and most of the production has a sulfur content of 1 percent or less. Compared with reserves, production of lignitic coals is small; only 2.9 million tons of lignite was produced in the United States in 1964. North Dakota, which has consistently produced more than 2 million tons of lignite per year, supplied about 90 percent of the 1964 total.

SUMMARY

The coal reserves of the United States occur in thousands of different seams that have widely varying sulfur contents. Sulfur, however, has not been a significant factor in the development of the coal industry. Both high- and low-sulfur coals have been mined for many years, with the production of coals of various sulfur contents depending chiefly upon their end use. The widespread distribution of our coal deposits, the ease in mining them, and good transportation systems also make available virtually all types of coals to practically all areas of the country.

Nearly two-thirds of the total remaining coal reserve of the United States is low-sulfur coal. Roughly, three-fourths of this low-sulfur coal is low rank (subbituminous and lignite), and the balance is bituminous and anthracite. Although low-sulfur coals may be found in virtually all parts of the United States, the preponderance, on a tonnage basis, occurs west of the Mississippi River. Of significance is the fact that when only high-rank coals (bituminous and anthracite) are considered, the States east of the Mississippi River contain 40 percent of the coals classified as "low sulfur" in the aforementioned definitions.

The bulk of the production of bituminous coal (roughly 95 percent) is mined in States east of the Mississippi River. The sulfur content of these coals varies considerably. In 1964, 36 percent, approximately 166 million tons, of the total bituminous coal mined in these States was low-sulfur coal. Approximately the same proportion of the total produced in these States could be considered medium-sulfur coal, while the remaining balance of about 28 percent had a high-sulfur content (more than 3 percent). Anthracite, which is mined primarily in Pennsylvania, generally contains less than 1 percent sulfur. Subbituminous and lignite, which are produced in the Western States and North Dakota, also are generally low in sulfur.

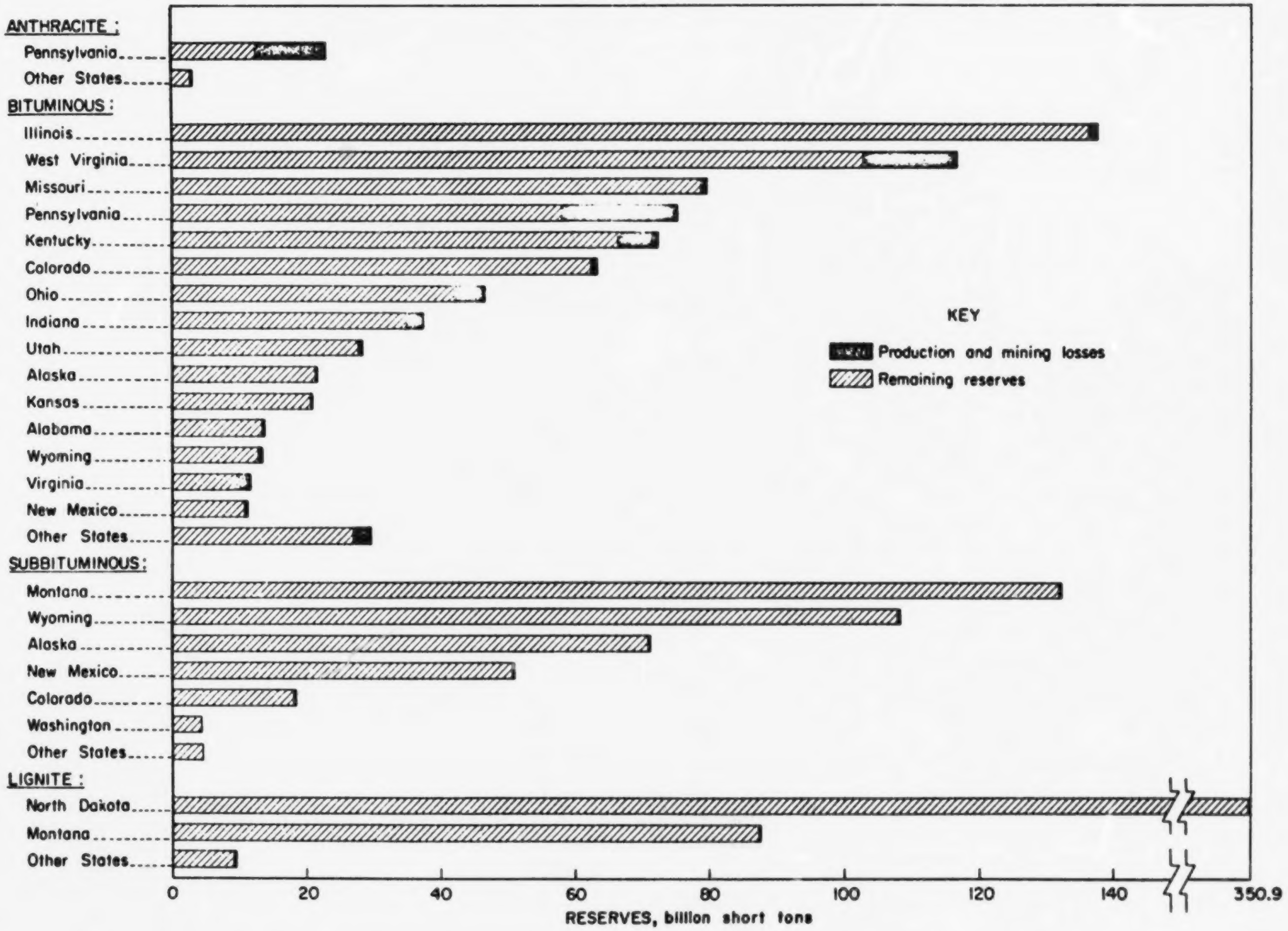

FIGURE 1. - Estimated Original and Remaining Coal Reserves by Rank, in the United States, Jan. 1, 1965.

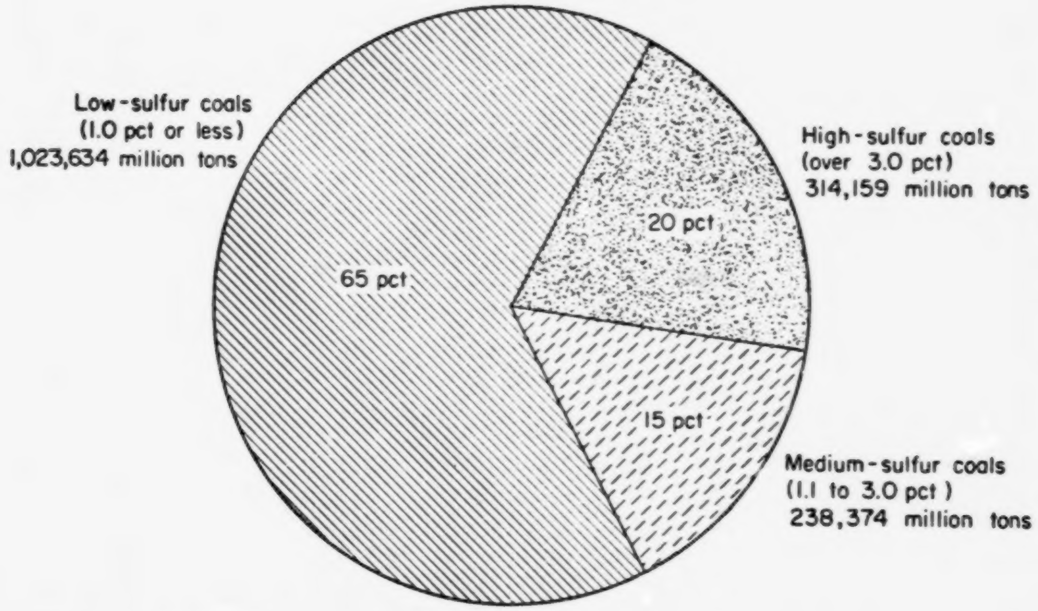

FIGURE 2. - Estimated Remaining Coal Reserves of All Ranks, by Sulfur Content, in the United States, Jan. 1, 1965.

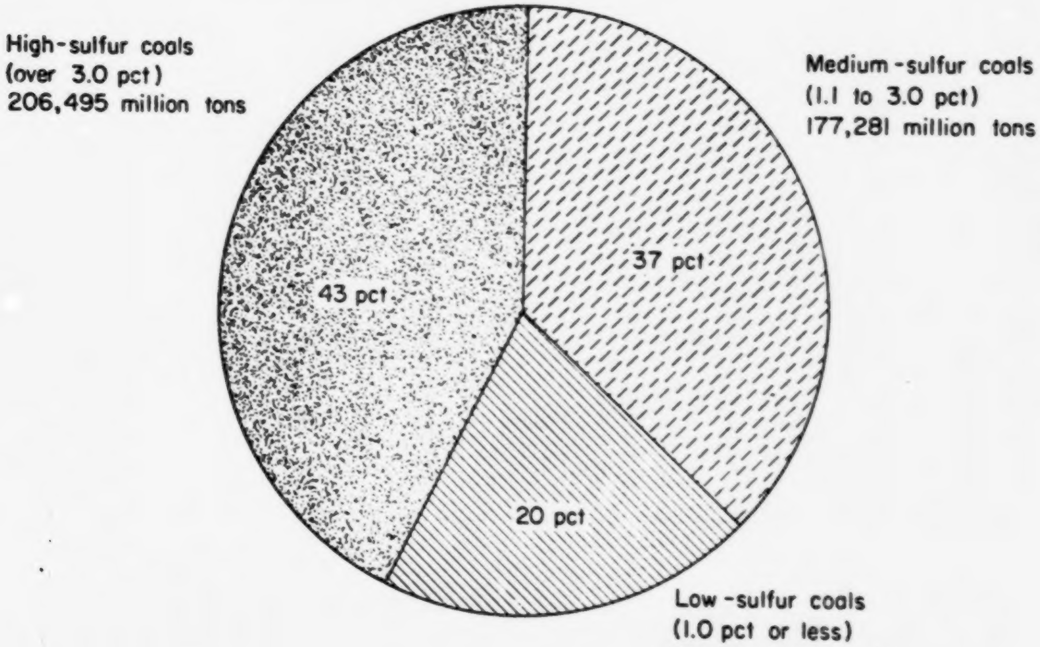

FIGURE 3. - Estimated Remaining Coal Reserves of All Ranks, by Sulfur Content, in States East of the Mississippi River, Jan. 1, 1965.

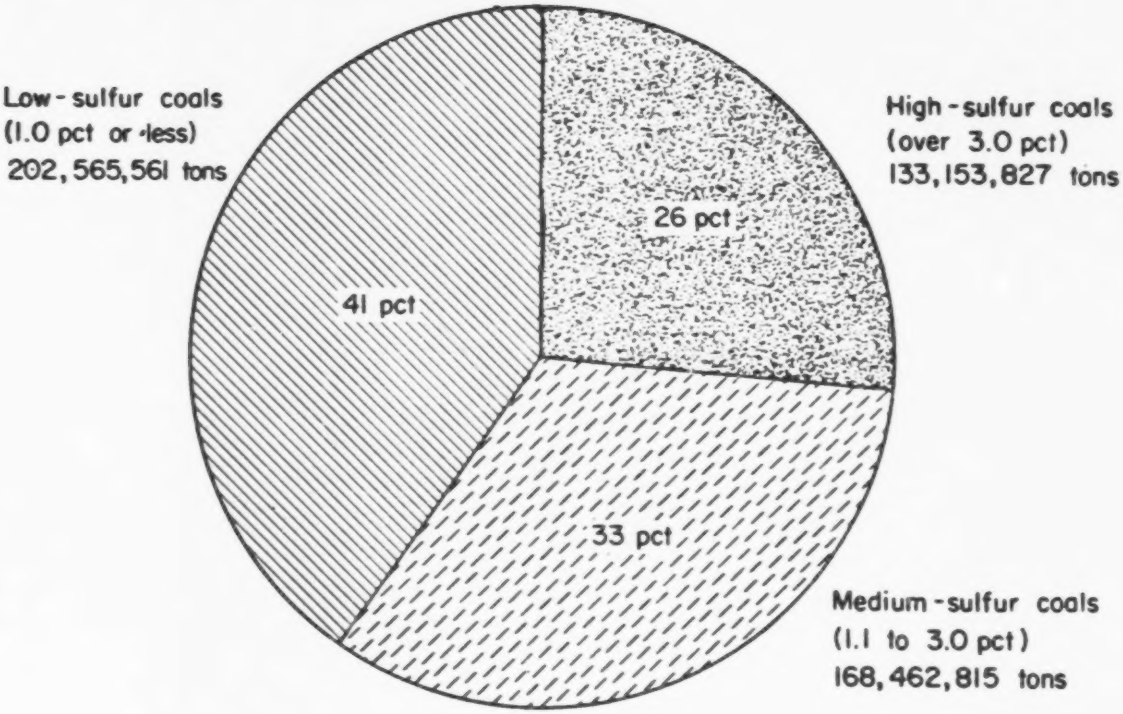

FIGURE 4. - Production of Coals of All Ranks, by Sulfur Content, in 1964.

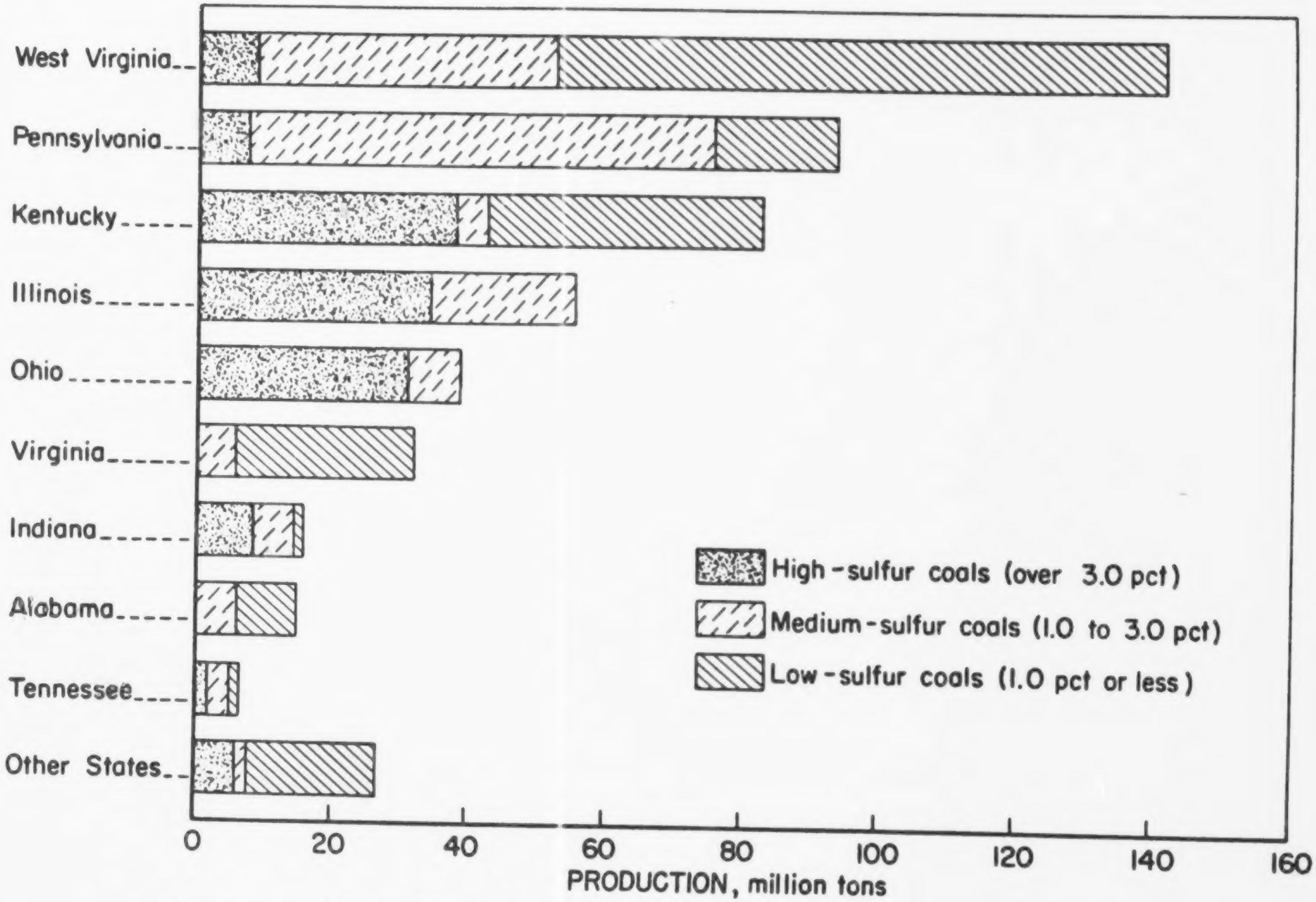

FIGURE 5. - Total Coal Production of All Ranks, by State and Sulfur Content, in the United States, in 1964.

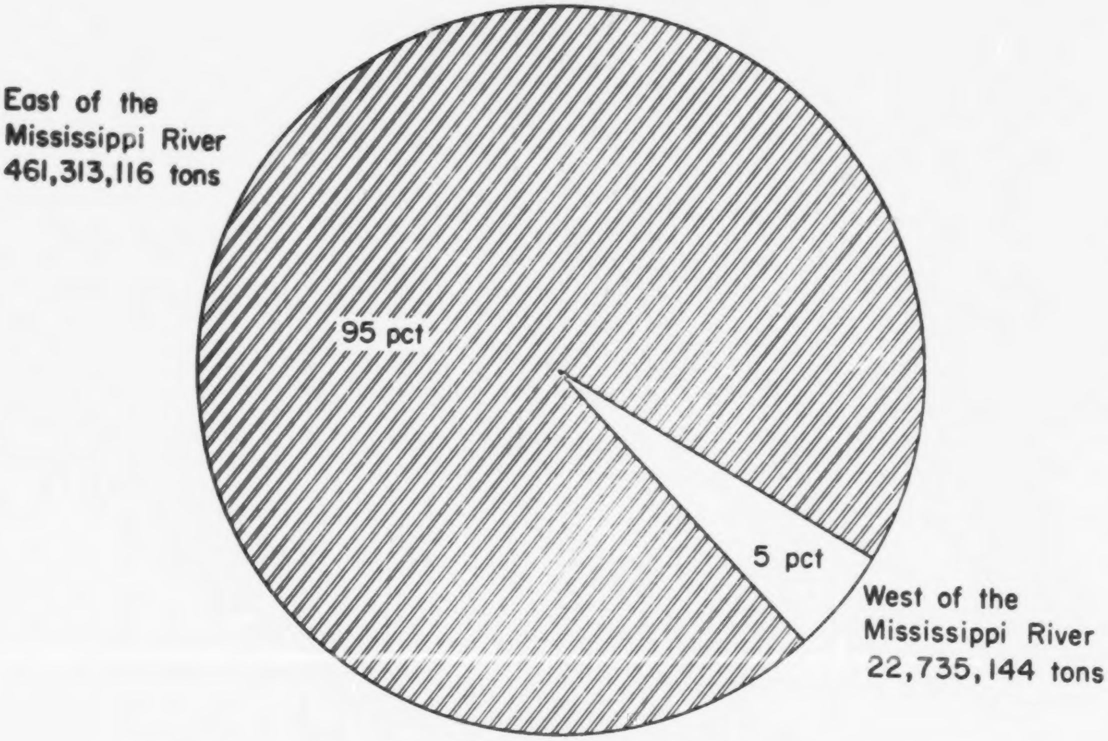

FIGURE 6. - Production of Bituminous Coals by Geographic Area, in 1964.

TABLE A-1. - Estimated remaining coal reserves of the United States, by rank, sulfur content, and State, on Jan. 1, 1965

(Million short tons)

Coal rank and State	Sulfur content, percent									Total
	0.7 or less	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	Over 4.0	
Bituminous coal:										
Alabama	889.2	1,189.3	5,421.7	5,182.8	458.8	417.4	-	-	18.6	13,577.8
Alaska	20,287.4	1,100.0	-	-	-	-	-	-	-	21,387.4
Arkansas	-	-	1,128.4	293.1	154.0	-	40.3	-	-	1,615.8
Colorado	25,178.3	37,237.2	-	-	-	-	-	-	-	62,415.5
Georgia	-	76.0	-	-	-	-	-	-	-	76.0
Illinois[2]	-	573.7	4,942.4	2,615.1	809.6	16,583.8	33,650.4	57,652.2	19,062.0	135,889.2
Indiana	197.5	173.0	3,645.2	4,248.8	3,543.4	4,110.5	10,872.8	5,105.9	2,944.0	34,841.1
Iowa	-	-	-	-	-	-	117.1	-	6,405.4	6,522.5
Kansas	-	-	519.9	519.7	1,038.7	2,070.6	4,148.0	8,287.3	4,153.8	20,738.0
Kentucky:										
West	-	-	1,119.6	162.0	336.3	3,793.6	12,759.3	13,643.3	5,081.3	36,895.4
East	13,639.9	8,491.9	2,286.8	1,658.8	1,158.3	2,154.4	24.7	-	-	29,414.8
Maryland	-	-	-	124.6	191.8	208.2	378.6	56.4	220.4	1,180.0
Michigan	-	-	-	-	-	-	-	205.0	-	205.0
Missouri	-	-	-	-	-	-	6,456.7	20,669.2	51,634.1	78,760.0
Montana	51.2	218.2	205.0	397.2	400.0	175.0	40.0	27.0	591.0	2,104.6
New Mexico	5,212.0	5,474.0	-	-	-	-	-	-	-	10,686.0
North Carolina	-	-	-	-	-	110.0	-	-	-	110.0
Ohio	-	611.0	369.0	2,110.2	2,750.4	7,810.5	9,785.3	10,148.2	8,439.4	42,024.0
Oklahoma	250.6	772.2	825.0	368.1	-	-	577.2	19.1	490.6	3,302.8
Oregon	-	14.0	-	-	-	-	-	-	-	14.0
Pennsylvania	44.0	1,154.4	7,624.4	12,424.9	19,689.5	9,995.6	5,287.6	1,150.5	580.6	57,951.5
Tennessee	3.3	160.9	715.9	258.7	178.2	190.5	219.7	43.8	68.5	1,839.5
Texas	-	-	-	-	7,978.0	-	-	-	-	7,978.0
Utah	8,551.4	13,584.0	-	1,524.9	-	-	-	-	3,997.7	27,658.0
Virginia	1,981.5	6,077.5	1,637.1	-	123.9	-	-	-	-	9,820.0
Washington	898.9	672.1	-	-	-	-	-	-	-	1,571.0
West Virginia	20,761.0	26,710.6	21,819.7	13,290.6	8,496.1	2,491.8	3,147.4	5,949.2	-	102,666.4
Wyoming	6,222.2	6,596.6	-	-	-	-	-	-	1.1	12,819.9
Other States[3]	-	616.0	-	-	-	-	-	-	-	616.0
Total	104,168.4	111,502.6	52,260.1	45,179.5	47,307.0	50,111.9	87,505.1	122,957.1	103,688.5	724,680.2
Percent of total	14.4	15.4	7.2	6.2	6.5	6.9	12.1	17.0	14.3	100.0
Subbituminous coal:										
Alaska	71,115.6	-	-	-	-	-	-	-	-	71,115.6
Colorado	13,320.8	4,908.7	-	-	-	-	-	-	-	18,229.5
Montana	94,084.4	36,728.0	0.5	1,303.7	-	-	-	-	-	132,116.6
New Mexico	38,735.0	12,000.0	-	-	-	-	-	-	-	50,735.0
Oregon	87.0	87.0	-	-	-	-	-	-	-	174.0
Utah	-	-	150.0	-	-	-	-	-	-	150.0
Washington	3,693.8	500.0	-	-	-	-	-	-	-	4,193.8
Wyoming	35,579.7	72,315.6	-	-	-	-	-	-	8.6	107,903.9
Other States[4]	-	4,047.0	-	-	-	-	-	-	-	4,047.0
Total	256,616.3	130,586.3	150.5	1,303.7	-	-	-	-	8.6	388,665.4
Percent of total	66.0	33.6	0.1	0.3	-	-	-	-	(5)	100.0
Lignite:										
Alabama	-	-	20.0	-	-	-	-	-	-	20.0
Arkansas	280.0	70.0	-	-	-	-	-	-	-	350.0
Montana	60,214.5	24,141.6	2,660.9	-	-	464.7	-	-	-	87,481.7
North Dakota	284,129.1	34,987.3	31,581.6	-	-	-	-	-	-	350,698.0
South Dakota	-	2,031.0	-	-	-	-	-	-	-	2,031.0
Texas	-	-	6,902.0	-	-	-	-	-	-	6,902.0
Washington	-	116.6	-	-	-	-	-	-	-	116.6
Other States[6]	-	42.0	-	-	-	-	-	-	-	42.0
Total	344,623.6	61,388.5	41,164.5	-	-	464.7	-	-	-	447,641.3
Percent of total	77.0	13.7	9.2	-	-	0.1	-	-	-	100.0
Anthracite:										
Alaska	2,101.0	-	-	-	-	-	-	-	-	2,101.0
Arkansas	-	-	-	145.5	286.3	-	-	-	-	431.8
Colorado	-	90.0	-	-	-	-	-	-	-	90.0
New Mexico	-	6.0	-	-	-	-	-	-	-	6.0
Pennsylvania	12,211.0	-	-	-	-	-	-	-	-	12,211.0
Virginia	335.0	-	-	-	-	-	-	-	-	335.0
Washington	5.0	-	-	-	-	-	-	-	-	5.0
Total	14,652.0	96.0	-	145.5	286.3	-	-	-	-	15,179.8
Percent of total	96.5	0.6	-	0.9	2.0	-	-	-	-	100.0
Grand total	720,060.3	303,573.4	93,575.1	46,628.7	47,593.3	50,576.6	87,505.1	122,957.1	103,697.1	1,576,166.7
Percent of total	45.7	19.3	5.9	3.0	3.0	3.2	5.5	7.8	6.6	100.0

[1] From U.S. Geological Survey Bulletin 1136 supplemented by data from Washington Division of Mines and Geology Bulletin 47 and Iowa Geological Survey Technical Paper 4, with adjustments for production and losses in mining through 1964.

[2] Sulfur levels assigned principally from data published in Illinois Geological Survey Report of Investigations No. 35. New study now in preparation indicates substantially lower tonnages of coals in the sulfur range of 2 percent or less than are shown in this report.

[3] Arizona, California, Idaho, Nebraska, Nevada.

[4] Arizona, California, Idaho.

[5] Less than 0.1 percent.

[6] California, Idaho, Louisiana, Nevada.

TABLE A-2. - Production of coal in the United States in 1964, by rank, sulfur content, and State

(Short tons)

Coal rank and State	Sulfur content, percent									Total
	0.7 and under	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.1 or more	
Bituminous coal:										
Alabama	421,254	8,457,875	4,259,443	1,296,882	-	-	-	-	-	14,435,454
Alaska	744,942	-	-	-	-	-	-	-	-	744,942
Arkansas	-	-	10,550	86,880	114,885	-	-	-	-	212,315
Colorado	4,347,011	8,234	-	-	-	-	-	-	-	4,355,245
Georgia	-	3,900	-	-	-	-	-	-	-	3,900
Illinois	-	-	6,127,976	10,418,025	(¹)	4,234,688	13,531,996	12,099,657	8,610,260	55,022,602
Indiana	112,032	(²)	3,589,828	(²)	3,091,274	69,890	-	7,347,053	864,554	15,074,631
Iowa	-	-	-	-	-	-	-	-	973,214	973,214
Kansas	-	-	-	6,258	-	458,467	458,467	340,217	-	1,263,409
Kentucky:										
East	32,666,124	7,733,985	2,877,863	1,380,167	233,213	(²)	-	-	-	44,891,352
West	-	-	187,038	-	13,573	-	10,263,283	21,791,860	5,600,065	37,855,819
Maryland	-	86,937	138,857	189,493	720,549	-	-	-	-	1,135,836
Missouri	-	-	-	-	-	-	-	208,090	3,045,340	3,253,430
Montana	45,906	-	-	-	-	-	-	-	-	45,906
New Mexico	2,969,472	-	-	-	-	-	-	-	-	2,969,472
Ohio	(³)	-	-	988,613	1,241,685	4,216,241	20,964,038	7,053,644	2,846,156	37,310,377
Oklahoma	266,099	155,120	275,418	-	-	-	8,267	-	323,092	1,027,996
Pennsylvania	-	-	25,353,558	30,960,393	6,059,591	7,135,378	5,109,356	1,325,702	586,780	76,530,758
Tennessee	762,023	754,724	2,139,549	166,718	561,789	147,974	1,457,628	-	-	5,990,405
Utah	2,248,566	2,416,309	-	19,221	-	-	-	-	35,747	4,719,843
Virginia	15,278,639	10,752,823	5,622,022	-	-	-	-	-	-	31,653,484
Washington	68,058	-	-	-	-	-	-	-	-	68,058
West Virginia	63,674,637	25,367,850	16,511,278	6,790,119	12,705,406	8,049,847	4,057,241	4,252,120	-	141,408,498
Wyoming	3,101,314	-	-	-	-	-	-	-	-	3,101,314
Total	126,706,077	55,737,757	67,093,380	52,302,769	24,741,965	24,312,485	55,850,276	54,418,343	22,885,208	484,048,260
Percent of total	26.2	11.5	13.9	10.8	5.1	5.0	11.5	11.3	4.7	100.0
Cumulative production[4]	126,706,077	182,443,834	249,537,214	301,839,983	326,581,948	350,894,433	406,744,709	461,163,052	484,048,260	-
Percent of total	26.2	37.7	51.6	62.4	67.5	72.5	84.0	95.3	100.0	-
Lignite:										
Montana	299,941	-	-	-	-	-	-	-	-	299,941
North Dakota	1,204,534	1,420,001	12,216	-	-	-	-	-	-	2,636,751
South Dakota	13,000	-	-	-	-	-	-	-	-	13,000
Total	1,517,475	1,420,001	12,216	-	-	-	-	-	-	2,949,692
Anthracite: Pennsylvania	17,184,251	-	-	-	-	-	-	-	-	17,184,251
Total, all ranks	145,407,803	57,157,758	67,105,596	52,302,769	24,741,965	24,312,485	55,850,276	54,418,343	22,885,208	504,182,203

[1] Included with "2.6 - 3.0" to avoid disclosing individual company data.

[2] Included with "1.1 - 1.5" to avoid disclosing individual company data.

[3] Included with "1.6 - 2.0" to avoid disclosing individual company data.

[4] By sulfur content; for example, the totals of columns 1 and 2 are added to give 182,443,834.

TABLE A-3. - Production of bituminous coal and lignite in the United States in 1964, according to sulfur content and producing district--Continued

(Short tons)

Producing district[1]	Sulfur content, percent									Total
	0.7 and under	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.1 or more	
District 3:										
West Virginia:										
Barbour	-	-	710,628	1,617,006	-	-	-	-	-	2,327,634
Braxton	-	-	-	-	(2)	(4)	-	-	-	(2)
Gilmer	-	-	-	-	(2)	-	-	-	-	(2)
Harrison	-	-	-	234,182	-	4,049,191	4,026,191	-	-	8,309,564
Lewis	-	-	-	-	-	169,759	-	-	-	169,759
Marion	-	-	5,134,985	-	6,632,828	-	-	-	-	11,767,813
Monongalia	-	-	38,775	2,871,101	1,804,164	3,813,793	-	-	-	8,527,833
Nicholas	3,852,564	1,711,710	-	-	-	-	-	-	-	5,564,274
Preston	-	-	938,108	1,658,089	938,109	-	-	-	-	3,534,306
Randolph	507,636	298,647	244,784	-	-	-	-	-	-	1,051,067
Taylor	-	-	-	-	429,750	-	-	-	-	429,750
Upshur	-	-	(5)	391,731	(2)	-	-	-	-	391,731
Webster	(6)	825,264	-	-	-	-	-	-	-	825,264
Undistributed	-	-	-	-	1,304,055	-	-	-	-	1,304,055
District total	4,360,200	2,835,621	7,067,280	6,772,109	11,108,906	8,032,743	4,026,191	-	-	44,203,050
District 4:										
Ohio:										
Athens	-	-	-	29,990	-	104,700	-	(2)	-	134,690
Belmont	-	-	-	-	-	-	7,834,638	-	-	7,834,638
Carroll	-	-	-	-	-	100,952	170,737	-	-	271,689
Columbiana	-	-	-	-	1,241,685	228,237	59,623	-	-	1,529,545
Coshocton	-	-	-	-	-	-	-	2,302,211	-	2,302,211
Gallia	-	-	-	-	-	614,674	-	-	-	614,674
Guernsey	-	-	-	-	(7)	-	304,904	(2)	-	304,904
Harrison	-	-	-	-	-	2,404,121	5,258,626	-	-	7,662,747
Hocking	-	-	-	(2)	-	15,967	-	34,440	-	50,407
Holmes	-	-	-	-	-	-	-	205,020	-	205,020
Jackson	(5)	-	-	276,198	-	(2)	(2)	17,875	133,783	427,856
Jefferson	-	-	-	-	-	181,632	4,115,736	(2)	-	4,297,368
Lawrence	-	-	-	-	-	(2)	(2)	-	-	(2)
Mahoning	-	-	-	535,319	-	-	243,279	(2)	-	778,598
Meigs	-	-	-	-	-	364,049	41,679	-	-	405,728
Morgan	-	-	-	-	-	-	10,425	929,825	929,824	1,870,074
Muskingum	-	-	-	-	-	(2)	101,694	(2)	-	101,694
Noble	-	-	-	-	-	-	-	966,938	1,755,496	2,722,434
Perry	-	-	-	-	-	-	-	(2)	-	(2)
Portage	-	-	-	-	-	-	62,628	-	-	62,628
Stark	-	-	-	-	-	-	73,010	306,903	27,053	406,966
Tuscarawas	-	-	-	-	-	(2)	2,414,234	-	-	2,414,234
Vinton	-	-	-	(2)	-	-	-	41,057	-	41,057
Wayne	-	-	-	-	-	-	52,062	-	-	52,062
Undistributed	-	-	-	147,106	-	201,909	220,763	2,249,375	-	2,819,153
District total	(5)	-	-	988,613	1,241,685	4,216,241	20,964,038	7,053,644	2,846,156	37,310,377
District 6:										
West Virginia:										
Brooke	-	-	-	-	1,030,011	-	-	-	-	1,030,011
Hancock	-	-	-	-	34,620	-	-	-	-	34,620
Marshall	-	-	-	-	-	-	-	(2)	-	(2)

TABLE A-3 Continued

Ohio	-	-	-	-	-	-	-	([2])	-	([2])
Undistributed	-	-	-	-	-	-	-	4,252,120	-	4,252,120
District total	-	-	-	-	1,064,631	-	-	4,252,120	-	5,316,751
District 7:										
Virginia:										
Buchanan	2,835,800	94,424	164,170	-	-	-	-	-	-	3,094,394
Montgomery	-	-	7,846	-	-	-	-	-	-	7,846
Tazewell	([6])	207,550	-	-	-	-	-	-	-	207,550
Total	2,835,800	301,974	172,016	-	-	-	-	-	-	3,309,790
West Virginia:										
Fayette	2,354,119	880,870	116,256	-	-	-	-	-	-	3,351,245
Greenbrier	944,542	-	-	-	-	-	-	-	-	944,542
McDowell	16,340,117	-	-	-	-	-	-	-	-	16,340,117
Mercer	1,462,394	-	-	-	-	-	-	-	-	1,462,394
Pocahontas	-	([8])	-	-	-	-	-	-	-	([8])
Raleigh	5,979,139	-	-	-	-	-	-	-	-	5,979,139
Wyoming	7,259,652	219,422	-	-	-	-	-	-	-	7,479,074
Total	34,339,963	1,100,292	116,256	-	-	-	-	-	-	35,556,511
District total	37,175,763	1,402,266	288,272	-	-	-	-	-	-	38,866,301
District 8:										
Kentucky:										
Bell	1,397,100	444,439	226,081	-	-	([7])	-	-	-	2,067,620
Boyd	-	41,164	-	-	-	-	-	-	-	41,164
Breathitt	260,164	-	-	-	-	-	-	-	-	260,164
Carter	27,006	-	-	-	-	-	-	-	-	27,006
Clay	538,073	-	946,717	-	-	-	-	-	-	1,484,790
Clinton	-	13,801	-	-	-	-	-	-	-	13,801
Elliott	13,852	-	-	-	-	-	-	-	-	13,852
Floyd	4,679,505	-	-	-	-	-	-	-	-	4,679,505
Harlan	3,537,911	2,103,945	-	-	-	-	-	-	-	5,641,856
Jackson	-	-	44,631	-	-	-	-	-	-	44,631
Johnson	196,246	65,340	-	-	-	-	-	-	-	261,586
Knott	1,484,059	9,693	-	564,910	-	-	-	-	-	2,058,662
Knox	27,121	128,162	111,655	-	-	-	-	-	-	266,938
Laurel	-	-	136,651	-	-	-	-	-	-	136,651
Lawrence	-	8,789	-	-	-	-	-	-	-	8,789
Lee	-	61,105	-	-	-	-	-	-	-	61,105
Leslie	1,806,531	-	-	-	-	-	-	-	-	1,806,531
Letcher	4,334,400	1,239,390	-	-	-	-	-	-	-	5,573,790
McCreary	33,012	432,697	-	-	-	-	-	-	-	465,709
Magoffin	14,534	-	-	81,271	-	-	-	-	-	95,805
Martin	-	-	-	-	196,526	-	-	-	-	196,526
Morgan	-	-	-	-	36,687	-	-	-	-	36,687
Owsley	-	-	-	9,200	-	-	-	-	-	9,200
Perry	3,219,332	-	-	724,786	-	-	-	-	-	3,944,118
Pike	11,097,278	2,360,932	1,377,837	-	-	-	-	-	-	14,836,047
Pulaski	-	158,212	-	-	-	-	-	-	-	158,212
Rockcastle	-	1,100	-	-	-	-	-	-	-	1,100
Wayne	-	52,500	-	-	-	-	-	-	-	52,500
Whitley	-	603,972	34,291	-	-	-	-	-	-	638,263
Wolfe	-	8,744	-	-	-	-	-	-	-	8,744
Total	32,666,124	7,733,985	2,877,863	1,380,167	233,213	([9])	-	-	-	44,891,352

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[1] As established under the Bituminous Coal Act of 1935.

[2] Included with "Undistributed" to avoid disclosing individual company data.

[4] Included with "Harrison County" to avoid disclosing individual company data.

[5] Included with "1.6 - 2.0" to avoid disclosing individual company data.

[6] Included with "0.8 - 1.0" to avoid disclosing individual company data.

[7] Included with "Columbiana County" to avoid disclosing individual company data.

[8] Included with "Wyoming County" to avoid disclosing individual company data.

[9] Included with "1.1 - 1.5" to avoid disclosing individual company data.

TABLE A-3 Continued

Producing district[1]	Sulfur content, percent									Total
	0.7 and under	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.1 or more	
District 8: (Con.)										
Tennessee:										
Anderson	-	-	1,055,570	-	-	-	726,820	-	-	1,782,390
Campbell	188,815	633,167	186,078	-	-	-	-	-	-	1,008,060
Claiborne	(2)	121,557	240,503	-	-	-	-	-	-	362,060
Cumberland	(2)	(10)	-	-	-	-	-	-	-	(2)
Fentress	-	-	-	-	50,328	-	-	-	-	50,328
Morgan	-	-	21,897	166,718	177,437	-	-	-	-	366,052
Overton	-	-	-	-	-	-	38,423	-	-	38,423
Putnam	-	-	-	-	-	-	477,776	-	-	477,776
Scott	-	-	238,071	-	-	147,974	214,609	-	-	600,654
Undistributed	18,764	-	-	-	-	-	-	-	-	18,764
Total	207,579	754,724	1,742,119	166,718	227,765	147,974	1,457,628	-	-	4,704,507
Virginia:										
Buchanan	2,766,249	4,875,121	3,765,841	-	-	-	-	-	-	11,407,211
Dickenson	4,955,030	1,585,926	1,187,525	-	-	-	-	-	-	7,728,481
Lee	115,098	356,192	-	-	-	-	-	-	-	471,290
Russell	1,438,015	453,976	7,587	-	-	-	-	-	-	1,899,578
Scott	-	-	4,300	-	-	-	-	-	-	4,300
Tazewell	29,037	(10)	-	-	-	-	-	-	-	29,037
Wise	3,139,410	3,179,634	484,753	-	-	-	-	-	-	6,803,797
Total	12,442,839	10,450,849	5,450,006	-	-	-	-	-	-	28,343,694
West Virginia:										
Boone	2,576,423	5,148,508	868,565	-	-	-	-	-	-	8,593,496
Clay	-	(9)	72,811	-	-	-	-	-	-	72,811
Fayette	2,055,195	331,920	-	-	-	-	-	-	-	2,387,115
Kanawha	2,005,635	5,607,284	3,388,898	-	-	-	-	-	-	11,001,817
Lincoln	-	-	18,363	-	-	-	-	-	-	18,363
Logan	8,666,534	3,310,953	3,908,140	-	-	-	-	-	-	15,885,627
Mason	-	-	-	-	457,871	-	-	-	-	457,871
McDowell	148,179	789,135	32,517	-	-	-	-	-	-	969,831
Mingo	1,090,595	4,517,950	-	-	-	-	-	-	-	5,608,545
Nicholas	1,129,661	1,162,483	-	-	-	-	-	-	-	2,292,144
Putnam	-	-	-	4,880	-	-	-	-	-	4,880
Raleigh	1,678,180	-	-	-	-	-	-	-	-	1,678,180
Wayne	-	30,389	-	-	-	-	-	-	-	30,389
Wyoming	5,624,072	533,315	-	-	-	-	-	-	-	6,157,387
Total	24,974,474	21,431,937	8,289,294	4,880	457,871	-	-	-	-	55,158,456
District total	70,291,016	40,371,495	18,359,282	1,55[illegible],765	918,849	147,974	1,457,628	-	-	133,098,009
District 9:										
Kentucky:										
Butler	-	-	187,038	-	-	-	-	-	-	187,038
Christian	-	-	-	-	13,573	-	-	-	-	13,573
Daviess	-	-	-	-	-	-	-	-	876,601	876,601
Hancock	-	-	-	-	-	-	-	-	1,000	1,000
Henderson	-	-	-	-	-	-	-	-	155,227	155,227
Hopkins	-	-	-	-	-	-	10,263,283	-	-	10,263,283

TABLE A-3 Continued

McLean	-	-	-	-	-	-	-	18,498	-	18,498
Muhlenberg	-	-	-	-	-	-	-	17,634,686	-	17,634,686
Ohio	-	-	-	-	-	-	-	-	4,567,237	4,567,237
Union	-	-	-	-	-	-	-	4,067,691	-	4,067,691
Webster	-	-	-	-	-	-	-	70,985	-	70,985
District total	-	-	187,038	-	13,573	-	10,263,283	21,791,860	5,600,065	37,855,819
District 10:										
Illinois:										
Adams	-	-	-	-	-	-	28,109	-	-	28,109
Bureau	-	-	-	-	-	-	(2)	-	-	(2)
Christian	-	-	-	-	-	-	-	-	(2)	(2)
Douglas	-	-	-	-	-	-	-	(2)	-	(2)
Franklin	-	-	-	(2)	-	-	-	-	-	(2)
Fulton	-	-	-	-	-	(2)	6,984,660	-	-	6,984,660
Gallatin	-	-	-	-	-	(2)	56,835	-	-	56,835
Greene	-	-	-	-	-	-	3,102	-	-	3,102
Grundy	-	-	-	-	-	-	(2)	-	-	(2)
Henry	-	-	-	-	-	-	-	-	(2)	(2)
Jackson	-	-	-	-	-	-	(2)	-	-	(2)
Jefferson	-	-	(2)	-	-	-	-	-	-	(2)
Knox	-	-	-	-	-	-	(2)	-	-	(2)
Logan	-	-	-	-	-	-	21,899	-	-	21,899
Macoupin	-	-	-	-	-	-	-	-	373,937	373,937
Madison	-	-	-	-	-	-	-	126,822	-	126,822
Menard	-	-	-	-	-	-	(2)	-	-	(2)
Mercer	-	-	-	-	-	-	-	-	(2)	(2)
Montgomery	-	-	-	-	-	-	-	-	(2)	(2)
Peoria	-	-	-	-	-	(2)	694,816	-	-	694,816
Perry	-	-	(2)	-	-	-	-	(2)	-	(2)
Randolph	-	-	-	-	-	-	-	(2)	-	(2)
St. Clair	-	-	-	-	-	-	-	5,770,464	-	5,770,464
Saline	-	-	-	-	-	1,667,110	-	2,360,501	-	4,027,611
Sangamon	-	-	-	-	-	-	-	-	79,286	79,286
Schuyler	-	-	-	-	-	(2)	-	-	-	(2)
Stark	-	-	-	-	-	-	-	(2)	-	(2)
Vermillion	-	-	-	-	(3)	(2)	-	-	-	(2)
Wabash	-	-	-	-	-	-	-	1,103	-	1,103
Washington	-	-	-	-	-	-	-	-	(2)	(2)
Will	-	-	-	-	-	-	-	-	(2)	(2)
Williamson	-	-	-	(2)	-	-	1,909,245	-	-	1,909,245
Undistributed	-	-	6,127,976	10,418,025	-	2,567,578	3,833,330	3,840,767	8,157,037	34,944,713
District total	-	-	6,127,976	10,418,025	(3)	4,234,688	13,531,996	12,099,657	8,610,260	55,022,602

[1] As established under the Bituminous Coal Act of 1935.
[2] Included with "Undistributed" to avoid disclosing individual company data.
[3] Included with "2.6 - 3.0" to avoid disclosing individual company data.
[9] Included with "1.1 - 1.5" to avoid disclosing indificual company data.
[10] Included with "0.7 and under" to avoid disclosing individual company data.

TABLE A-3 Continued

Producing district[1]	Sulfur content, percent									Total
	0.7 and under	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.1 or more	
District 11:										
Indiana:										
Clay	100,932	-	-	-	-	-	-	-	864,554	965,486
Daviess	11,100	-	-	-	-	-	-	-	-	11,100
Dubois	-	-	-	-	-	-	-	10,500	-	10,500
Fountain	-	-	-	-	-	-	-	(11)	-	(11)
Gibson	-	-	-	-	-	-	-	561,329	-	561,329
Greene	-	-	1,552,712	-	-	-	-	-	-	1,552,712
Knox	-	-	-	-	-	64,899	-	-	-	64,899
Owen	-	(9)	(2)	-	-	-	-	-	-	(2)
Parke	-	-	-	-	7,416	-	-	-	-	7,416
Pike	-	-	-	-	-	-	-	2,268,465	-	2,268,465
Spencer	-	-	-	-	70,445	-	-	-	-	70,445
Sullivan	-	-	(2)	-	-	-	-	784,848	-	784,848
Vermillion	-	-	-	-	-	4,991	-	-	-	4,991
Vigo	-	-	(2)	(9)	-	-	-	378,193	(12)	378,193
Warrick	-	-	-	-	3,013,413	-	-	3,343,718	-	6,357,131
Undistributed	-	-	2,037,116	-	-	-	-	-	-	2,037,116
District total	112,032	(9)	3,589,828	(9)	3,091,274	69,890	-	7,347,053	864,554	15,074,631
District 12:										
Iowa:										
Appanoose	-	-	-	-	-	-	-	-	39,582	39,582
Lucas	-	-	-	-	-	-	-	-	49,723	49,723
Mahaska	-	-	-	-	-	-	-	-	318,486	318,486
Marion	-	-	-	-	-	-	-	-	397,687	397,687
Monroe	-	-	-	-	-	-	-	-	94,515	94,515
Van Buren	-	-	-	-	-	-	-	-	16,931	16,931
Wapello	-	-	-	-	-	-	-	-	56,290	56,290
District total	-	-	-	-	-	-	-	-	973,214	973,214
District 13:										
Alabama:										
Bibb	-	230,073	-	-	-	-	-	-	-	230,073
Blount	-	-	2,596	-	-	-	-	-	-	2,596
Cullman	-	-	8,452	-	-	-	-	-	-	8,452
Etowah	-	-	126,560	-	-	-	-	-	-	126,560
Jackson	-	-	163,809	-	-	-	-	-	-	163,809
Jefferson	421,254	5,302,435	1,581,850	149,777	-	-	-	-	-	7,455,316
Marion	-	-	319,888	-	-	-	-	-	-	319,888
St. Clair	-	-	-	4,000	-	-	-	-	-	4,000
Shelby	-	686,879	-	-	-	-	-	-	-	686,879
Tuscaloosa	-	-	1,101,488	-	-	-	-	-	-	1,101,488
Walker	-	2,238,488	801,300	1,143,105	-	-	-	-	-	4,182,893
Winston	-	-	153,500	-	-	-	-	-	-	153,500
Total	421,254	8,457,875	4,259,443	1,296,882	-	-	-	-	-	14,435,454
Georgia: Walker	-	3,900	-	-	-	-	-	-	-	3,900

TABLE A-3 Continued

Tennessee:										
Bledsoe	-	-	9,719	-	-	-	-	-	-	9,719
Grundy	-	-	-	-	334,024	-	-	-	-	334,024
Hamilton	-	-	28,018	-	(13)	-	-	-	-	28,018
Marion	530,044	-	8,200	-	-	-	-	-	-	538,244
Rhea	24,400	-	-	-	-	-	-	-	-	24,400
Sequatchie	-	-	67,141	-	-	-	-	-	-	67,141
Van Buren	-	-	284,352	-	-	-	-	-	-	284,352
Total	554,444	-	397,430	-	334,024	-	-	-	-	1,285,898
District total	975,698	8,461,775	4,656,873	1,296,882	334,024	-	-	-	-	15,725,252
District 14:[14]										
Arkansas:										
Franklin	-	-	-	86,880	-	-	-	-	-	86,880
Johnson	-	-	-	-	114,885	-	-	-	-	114,885
Sebastian	-	-	10,550	-	-	-	-	-	-	10,550
District total	-	-	10,550	86,880	114,885	-	-	-	-	212,315
District 15:										
Kansas:										
Bourbon, Cherokee, Crawford	-	-	-	6,258	-	458,467	458,467	340,217	-	1,263,409
Missouri:										
Adair	-	-	-	-	-	-	-	-	27,415	27,415
Boone	-	-	-	-	-	-	-	-	(2)	(2)
Callaway	-	-	-	-	-	-	-	-	27,957	27,957
Clark	-	-	-	-	-	-	-	-	(2)	(2)
Dade	-	-	-	-	-	-	-	17,000	-	17,000
Henry	-	-	-	-	-	-	-	-	(2)	(2)
Macon	-	-	-	-	-	-	-	-	(2)	(2)
Putnam	-	-	-	-	-	-	-	-	136,754	136,754
St. Clair	-	-	-	-	-	-	-	191,090	-	191,090
Vernon	-	-	-	-	-	-	-	-	52,964	52,964
Undistributed	-	-	-	-	-	-	-	-	2,800,250	2,800,250
Total	-	-	-	-	-	-	-	208,090	3,045,340	3,253,430
Oklahoma:										
Craig	-	-	-	-	-	-	-	-	323,092	323,092
Muskogee	-	-	-	-	-	-	1,350	-	-	1,350
Okmulgee	-	-	1,700	-	-	-	-	-	-	1,700
Haskell,[14] LeFlore,[14] Rogers	266,099	155,120	273,718	-	-	-	6,917	-	-	701,854
Total	266,099	155,120	275,418	-	-	-	8,267	-	323,092	1,027,996
District total	266,099	155,120	275,418	6,258	-	458,467	466,734	548,307	3,368,432	5,544,835
District 16:[15]										
Colorado: Weld	765,447	-	-	-	-	-	-	-	-	765,447

[1] As established under the Bituminous Coal Act of 1935.

[2] Included with "Undistributed" to avoid disclosing individual company data.

[9] Included with "1.1 - 1.5" to avoid disclosing individual company data.

[11] Included with "Gibson County" to avoid disclosing individual company data.

[12] Included with "Clay County" to avoid disclosing individual company data.

[13] Included with "Grundy County" to avoid disclosing individual company data.

[14] Haskell and LeFlore Counties, Okla., are in District 14 but are included with "District 15: Oklahoma" to avoid disclosing individual company data.

[15] El Paso County is included with "District 17, Colorado: Undistributed" to avoid disclosing individual company data.

TABLE A-3 Continued

Producing district[1]	Sulfur content, percent									Total
	0.7 and under	0.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.1 or more	
District 17:[15]										
Colorado:										
Delta	62,576	-	-	-	-	-	-	-	-	62,576
Fremont	292,704	-	-	-	-	-	-	-	-	292,704
Garfield	-	8,234	-	-	-	-	-	-	-	8,234
Gunnison	462,985	-	-	-	-	-	-	-	-	462,985
Huerfano	49,921	-	-	-	-	-	-	-	-	49,921
LaPlata	26,780	-	-	-	-	-	-	-	-	26,780
Las Animas	801,484	-	-	-	-	-	-	-	-	801,484
Mesa	(2)	-	-	-	-	-	-	-	-	(2)
Moffat	(2)	-	-	-	-	-	-	-	-	(2)
Montrose	(2)	-	-	-	-	-	-	-	-	(2)
Pitkin	(2)	-	-	-	-	-	-	-	-	(2)
Rio Blanco	(2)	-	-	-	-	-	-	-	-	(2)
Routt	(2)	-	-	-	-	-	-	-	-	(2)
Undistributed	1,885,114	-	-	-	-	-	-	-	-	1,885,114
Total	3,581,564	8,234	-	-	-	-	-	-	-	3,589,798
New Mexico: Colfax	402,237	-	-	-	-	-	-	-	-	402,237
District total	3,983,801	8,234	-	-	-	-	-	-	-	3,992,035
District 18: New Mexico: McKinley, Rio Arriba, Sandoval, San Juan	2,567,235	-	-	-	-	-	-	-	-	2,567,235
District 19:										
Wyoming:										
Campbell	488,846	-	-	-	-	-	-	-	-	488,846
Carbon	446,509	-	-	-	-	-	-	-	-	446,509
Converse	(2)	-	-	-	-	-	-	-	-	(2)
Hot Springs	11,788	-	-	-	-	-	-	-	-	11,788
Lincoln	(2)	-	-	-	-	-	-	-	-	(2)
Sheridan	431,521	-	-	-	-	-	-	-	-	431,521
Sweetwater	(2)	-	-	-	-	-	-	-	-	(2)
Undistributed	1,722,650	-	-	-	-	-	-	-	-	1,722,650
District total	3,101,314	-	-	-	-	-	-	-	-	3,101,314
District 20:										
Utah:										
Carbon	1,591,489	2,416,309	-	-	-	-	-	-	-	4,007,798
Emery	592,077	(18)	-	-	-	-	-	-	-	592,077
Iron	18,000	-	-	-	-	-	-	-	35,747	53,747
Kane	-	-	-	1,883	-	-	-	-	-	1,883
Sevier	47,000	-	-	-	-	-	-	-	-	47,000
Summitt	-	-	-	17,238	-	-	-	-	-	17,338
District total	2,248,566	2,416,309	-	19,221	-	-	-	-	35,747	4,719,843

TABLE A-3 Continued

District 21:										
North Dakota (lignite):										
Adams	-	15,637	-	-	-	-	-	-	-	15,637
Bowman	-	139,867	-	-	-	-	-	-	-	139,867
Burke	(2)	-	-	-	-	-	-	-	-	(2)
Burleigh	7,988	-	-	-	-	-	-	-	-	7,988
Dunn	2,809	-	-	-	-	-	-	-	-	2,809
Grant	-	19,930	-	-	-	-	-	-	-	19,930
Hettinger	2,919	-	-	-	-	-	-	-	-	2,919
McLean	47,842	-	-	-	-	-	-	-	-	47,842
Mercer	-	(2)	-	-	-	-	-	-	-	(2)
Morton	-	-	12,216	-	-	-	-	-	-	12,216
Oliver	-	(2)	-	-	-	-	-	-	-	(2)
Stark	88,848	-	-	-	-	-	-	-	-	88,848
Ward	(2)	-	-	-	-	-	-	-	-	(2)
Williams	1,867	-	-	-	-	-	-	-	-	1,867
Undistributed	1,052,261	1,244,567	-	-	-	-	-	-	-	2,296,828
Total	1,204,534	1,420,001	12,216	-	-	-	-	-	-	2,636,751
South Dakota (lignite)	13,000	-	-	-	-	-	-	-	-	13,000
District total	1,217,534	1,420,001	12,216	-	-	-	-	-	-	2,649,751
District 22:										
Montana:										
Bituminous coal	45,906	-	-	-	-	-	-	-	-	45,906
Lignite	299,941	-	-	-	-	-	-	-	-	299,941
District total	345,847	-	-	-	-	-	-	-	-	345,847
District 23:										
Washington: King, Lewis, Thurston	68,058	-	-	-	-	-	-	-	-	68,058
Alaska	744,942	-	-	-	-	-	-	-	-	744,942
District total	813,000	-	-	-	-	-	-	-	-	813,000
Grand total	128,223,552	57,157,758	67,105,596	52,302,769	24,741,965	24,312,485	55,850,276	54,418,343	22,885,208	486,997,952

[1] As established under the Bituminous Coal Act of 1935.

[2] Included with "Undistributed" to avoid disclosing individual company data.

[15] El Paso County is included with "District 17, Colorado: Undistributed" to avoid disclosing individual company data.

[16] Included with "Carbon County" to avoid disclosing individual company data.

ANALYSES OF TIPPLE AND DELIVERED SAMPLES *

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966

State, county, town, and mine	Bed	Size of coal 1/	Approximate tons sampled	Kind of sample 2/	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses 3/	Ash-softening temperature, ° F	Number of ash-softening temperatures 3/	Free-swelling index 3/	Hardgrove grindability index 3/
						Dry coal														
					Moisture, as-received coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as-received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ALABAMA																				
Walker County																				
Jasper:																				
Drummond	Black Creek	Run-of-mine, crushed	66,242	D	4.5	36.6	55.1	8.3	1.5	-	-	-	-	12,870	13,480	68	2,180	1	-	-
Do	.do	1-1/4- by 1/4-inch (W)	12,282	D	4.7	39.7	55.8	4.5	1.7	-	-	-	-	13,510	14,180	21	2,200	7	4½(2) 5(1) 5½(4)	-
Townley: Townley		7- by 3-inch	12,033	D	3.7	34.0	54.5	11.5	.6	-	-	-	-	12,500	12,980	19	-	-	-	-
ALASKA–See page 31																				
ARKANSAS																				
Franklin County																				
Charleston: Charleston	Charleston	Run-of-mine, crushed to 6-inch	500	T	2.0	18.6	72.8	8.6	4.1	-	-	-	-	13,880	14,160	1	2,380	1	9(1)	109
Johnson County																				
Clarksville:																				
Clarksville No. 2	Hartshorne	Run-of-mine, crushed to 7/8-inch	75	T	4.6	12.7	78.8	8.5	2.7	3.7	83.1	1.6	.4	13,500	14,150	1	2,140	1	-	80
Dixie Strip	Upper Hartshorne	Run-of-mine, crushed to 3/4-inch (AC).	80	T	4.6	12.5	81.1	6.4	3.0	-	-	-	-	13,850	14,520	1	2,190	1	-	82
Do	Lower Hartshorne	..do	100	T	4.9	12.2	80.5	7.3	2.0	-	-	-	-	13,680	14,380	1	2,140	1	-	82
Wilton No. 4	Upper Hartshorne	Run-of-mine, crushed to 2-inch	100	T	4.3	11.2	80.9	7.9	3.7	-	-	-	-	13,590	14,200	1	2,230	1	-	75
Do	Lower Hartshorne	..do	80	T	4.8	12.6	81.3	6.1	.8	-	-	-	-	13,860	14,560	1	2,250	1	-	75
Johnson	Hartshorne	Run-of-mine, crushed to 3/4-inch	80	T	2.6	12.9	78.0	9.1	1.7	-	-	-	-	13,690	14,060	1	2,270	1	-	78
Prairie	.do	Run-of-mine, crushed to 2-inch	80	T	2.7	12.5	77.7	9.8	2.8	3.6	81.2	1.6	1.0	13,480	13,850	1	2,240	1	-	80
Sebastian County																				
Hackett: Four Way	.do	Run-of-mine	20	T	3.3	17.5	77.0	5.5	.9	4.4	85.6	1.8	1.8	14,330	14,820	1	2,230	1	9(1)	111
COLORADO																				
Delta County																				
Bowie: King		1-1/4- by 1/4-inch	1,850	D	4.0	41.2	52.5	6.3	.6	-	-	-	-	13,190	13,740	12	2,860	3	-	-
Fremont County																				
Florence:																				
Corley Strip		..do	290	D	9.4	36.7	47.5	15.8	.4	-	-	-	-	10,320	11,390	2	-	-	-	-
Pioneer Canon		8- by 2-inch (W)	50	T	11.0	38.2	50.3	11.5	.4	-	-	-	-	10,590	11,900	1	2,390	1	-	-
Do		8- by 3-inch	9,999	D	10.6	37.3	53.0	9.7	.4	-	-	-	-	10,900	12,190	12	-	-	-	-
Do		1-1/4- by 3/8-inch (W)	65	T	11.5	37.2	47.0	15.8	.5	-	-	-	-	10,020	11,320	1	2,430	1	-	-
Do		1-1/4- by 1/4-inch	14,279	D	12.0	36.9	49.4	13.7	.4	-	-	-	-	10,230	11,630	38	2,400	11	-	-
Do		Modified 2-inch by 0 (W) (1-1/4- by 3/8-inch removed).	100	T	11.9	36.3	48.1	15.6	.4	-	-	-	-	9,880	11,220	1	2,390	1	-	46
Vento		8- by 3-inch	4,929	D	11.1	37.3	54.7	8.0	.4	-	-	-	-	11,140	12,540	9	-	-	-	-
Do		1-1/4- by 1/4-inch	1,008	D	11.3	36.5	49.8	13.7	.4	-	-	-	-	10,390	11,720	3	2,360	2	-	-
Gunnison County																				
Somerset:																				
Bear		6-inch lump	150	T	5.8	41.9	54.5	3.6	.4	-	-	-	-	13,130	13,940	1	2,300	1	-	-
Do		1-1/4- by 5/16-inch (OT)	150	T	5.9	40.0	51.9	8.1	.5	-	-	-	-	12,480	13,260	1	2,520	1	3(1)	-
Do		Modified 1-1/2-inch by 0 (6- by 1-1/2-inch, crushed to 1-1/2-inch, 1-1/4- by 5/16-inch removed).	400	T	6.9	39.6	51.5	8.9	.5	-	-	-	-	12,170	13,070	1	2,570	1	-	46

* Aresco, A. J. and Janus, J. B., Bureau of Mines RI 6904, 1967.

Huerfano County																				
Walsenburg:																				
Delcarbon		3-inch lump	25	T	6.[illegible]	41.2	50.8	8.0	.7	-	-	-	-	12,040	12,890	1	2,440	1	-	-
Do		1-1/4- by 1/4-inch (3- by 1-1/4-inch, crushed to 1-1/4-inch).	20	T	6.1	40.7	49.0	10.3	.8	-	-	-	-	11,820	12,590	1	2,350	1	-	43
Do		1/4-inch by 0	10	T	6.5	40.7	48.5	10.8	.8	-	-	-	-	11,530	12,330	1	2,280	1	-	-
Mesa County																				
Palisade:																				
Roadside	Cameo	Run-of-mine, crushed to 1-1/2-inch	35	T	8.2	38.[illegible]	48.5	13.3	.8	-	-	-	-	11,230	12,230	1	2,910+	1	1½(1)	54
Do	do	8-inch lump	5	T	9.1	39.3	51.4	9.3	.[illegible]	5.0	73.2	1.5	10.3	11,640	12,810	1	2,550	1	-	-
Do	do	1- by 1/4-inch (OT)	15	T	8.4	38.1	47.2	14.7	.9	-	-	-	-	10,920	11,920	1	2,790	1	-	-
Moffat County																				
Craig:																				
Red Wing		8-inch lump	10	T	12.4	44.3	51.5	4.[illegible]	.3	-	-	-	-	11,460	13,080	1	2,500	1	-	-
Do		8- by 3-inch	22	T	11.6	44.5	52.[illegible]	3.3	.4	-	-	-	-	11,640	13,170	1	2,510	1	-	-
Do		3- by 2-1/4-inch	38	T	11.3	46.1	50.6	3.3	.4	-	-	-	-	11,740	13,240	1	2,520	1	-	53
Do		1-1/4- by 1/4-inch (OT) (2-1/4- by 1-1/4-inch, crushed to 1-1/4-inch).	70	T	12.2	44.5	51.9	3.6	.4	-	-	-	-	11,570	13,180	1	2,520	1	-	-
Do		1/4-inch by 0	100	T	14.7	43.9	52.0	4.1	.5	-	-	-	-	11,110	13,030	1	2,270	1	-	-
Wise Hill No. 3		Run-of-mine, crushed to 1-1/4-inch	170	T	16.[illegible]	39.4	54.8	5.8	.5	5.1	72.8	1.5	14.3	10,630	12,660	1	2,260	1	-	-
Routt County																				
Oak Creek:																				
Elna	Lennox	1-1/4- by 1/4-inch (OT) (Run-of-mine, crushed to 1-1/4-inch	345	T	9.7	45.5	50.4	4.1	.5	-	-	-	-	11,980	13,270	1	2,050	1	-	-
Do	do	1/4-inch by 0	180	T	11.0	43.9	51.6	4.5	2.4	-	-	-	-	11,670	13,110	1	1,990	1	1(1)	-
Do	Wadge	Run-of-mine, crushed to 2-inch	1,900	T	10.7	41.5	48.8	9.7	.8	-	-	-	-	11,100	12,330	1	2,690	1	-	47
D	do	8- by 3-inch	1,003	D	9.4	40.2	52.7	7.1	.6	-	-	-	-	11,540	12,750	4	-	-	-	-
Do	do	1-1/4- by 1/4-inch	2,401	D	8.7	42.1	49.3	8.6	.8	-	-	-	-	11,480	12,570	7	2,850	2	-	-
Weld County																				
Erie:																				
Eagle		8- by 3-inch	1,612	D	20.4	38.9	56.1	5.0	.3	-	-	-	-	10,080	12,660	12	2,100	1	-	-
Do		1-1/4-inch by 0	11,273	D	21.7	38.4	56.1	5.5	.3	-	-	-	-	9,8[illegible]0	12,58[illegible]	45	2,070	6	-	-
Imperial		8- by 3-inch	557	D	21.8	38.5	56.5	5.0	.3	-	-	-	-	9,800	12,640	4	-	-	-	-
Do		1-1/4-inch by 0	3,657	D	22.0	38.7	54.6	6.7	.3	-	-	-	-	9,690	12,4[illegible]	8	2,130	1	-	-
ILLINOIS																				
Fulton County																				
Vermont:																				
Bun Sp[illegible]	No. 2	2- by 1-1/4-inch (W)	27,018	D	13.[illegible]	44.6	49.4	6.0	3.0	-	-	-	-	11,770	13,660	28	2,020	6	3([illegible]) 3½(4)	-
Do	do	1-1/4- by 1/4-inch (W)	16,610	D	13.6	44.9	48.[illegible]	6.[illegible]	3.0	-	-	-	-	11,760	13,620	19	2,090	6	2(1) 2½(3) 3(2)	-
Henry County																				
Atkinson: Wacco	No. 6	3/4-inch by 0 (W)	40,434	D	18.0	42.3	48.9	8.8	2.8	-	-	-	-	10,560	12,870	45	2,100	7	2(1) 2½(1) 3(2) 4(3)	-
Kankakee County																				
South Wilmington (Grundy County):																				
Northern Illinois		1-1/2-inch by 28-mesh (W)	25,869	D	15.1	44.6	48.5	6.7	2.8	-	-	-	-	11,440	13,480	30	2,040	9	2(2) 2½(3) 3(4)	-

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1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal 1/	Approximate tons sampled	Kind of sample 1/	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses 2/	Ash-softening temperature, ° F	Number of ash-softening temperatures 2/	Free-swelling index 2/	Hardgrove grindability index 2/
					Moisture, as-received coal	Dry coal														
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as-received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ILLINOIS—Continued																				
Kankakee County--Continued																				
South Wilmington (Grundy County) (Continued): Northern Illinois (Continued).	....	1-inch by 28-mesh (W)............	50,712	D	14.8	44.5	48.2	7.3	2.8	-	-	-	-	11,370	13,350	52	2,050	3	2½(1) 3(1) 3½(1)	-
Peoria County																				
Glasford: Banner...........	No. 2................	1-1/4- by 1/4-inch (W)...........	594	D	13.1	48.3	45.7	6.0	3.2	-	-	-	-	11,910	13,700	3	2,030	2	2½(1) 3(1)	-
Perry County																				
Duquoin: Fidelity...........	No. 6................	..do..............................	14,963	D	9.9	41.0	48.9	10.1	3.2	-	-	-	-	11,520	12,780	16	2,080	5	2½(1) 3(2) 3½(2)	-
Randolph County																				
Percy:																				
Streamline.................	.do..................	6- by 3-inch (W).................	9,970	D	8.4	41.7	47.6	10.7	3.8	-	-	-	-	11,540	12,610	12	-	-	-	-
Do.........................	.do..................	1-1/2- by 1/4-inch (W)...........	1,033	D	9.4	42.8	47.8	9.4	3.3	-	-	-	-	11,650	12,860	2	2,180	2	4(2)	-
Sparta:																				
Spartan....................	.do..................	3/4-inch by 10-mesh (W)..........	2,554	D	12.1	42.1	47.5	10.4	3.0	-	-	-	-	11,180	12,720	11	2,140	5	3(1) 3½(2) 4(1)	-
Do.........................	.do..................	3/4-inch by 28-mesh (W)..........	6,891	D	10.6	41.8	47.6	10.6	3.2	-	-	-	-	11,300	12,640	13	2,120	6	4½(1) 2½(4) 3½(2)	-
Saint Clair County																				
Belleville:																				
Belle Valley...............	.do..................	3/4-inch by 10-mesh (W)..........	2,496	D	11.6	45.1	45.3	9.6	3.8	-	-	-	-	11,410	12,910	3	2,100	3	2(1) 3½(2)	-
Do.........................	.do..................	3/4-inch by 28-mesh (W and OT)....	18,953	D	11.3	44.8	45.3	9.9	3.7	-	-	-	-	11,400	12,850	24	2,120	9	3(6) 3½(3)	-
Midwest....................	.do..................	3/4-inch by 28-mesh (W)..........	1,208	D	11.4	43.2	46.7	10.1	3.5	-	-	-	-	11,350	12,810	14	2,150	4	2½(1) 3½(1) 4(1)	-
Do.........................	.do..................	1-1/2-inch by 0 (W)..............	203	D	12.7	42.6	46.3	11.1	3.5	-	-	-	-	11,070	12,680	1	-	-	-	-
Do.........................	.do..................	1-1/4-inch by 0 (W)..............	10,466	D	11.0	42.7	46.4	10.9	3.8	-	-	-	-	11,290	12,680	15	2,120	4	3½(3)	-
Freeburg: River King........	.do..................	1-inch by 28-mesh (W)............	902	D	11.3	41.8	47.2	11.0	3.3	-	-	-	-	11,280	12,720	1	-	-	-	-
Saline County																				
Harrisburg:																				
Sahara No. 5 (dock coal)...	No. 5................	1-1/4- by 1/4-inch (W)...........	1,907	D	7.6	36.9	55.5	7.5	1.5	-	-	-	-	12,570	13,610	4	2,230	2	-	-
Stark County																				
Wyoming: Allendale..........	No. 6................	2- by 1-1/4-inch (W).............	32,514	D	17.2	43.5	49.6	6.9	3.0	-	-	-	-	10,950	13,220	35	2,060	7	2(2) 2½(3) 3(2)	-

Vermilion County																				
Danville:																				
Harmattan	No. 7	3/4- by 1/4-inch (W)	11,995	D	11.9	46.5	44.9	8.6	2.9	-	-	-	-	11,620	13,130	26	2,070	6	2½(1) 3(4)	-
Do	.do	3/4-inch by 28-mesh (W)	47,750	D	13.7	46.0	44.9	9.1	3.0	-	-	-	-	11,330	13,130	54	2,080	9	2(2) 3(4) 3½(3)	-
V-Day	No 6	7-inch lump	22	T	13.7	41.0	50.1	8.9	1.8	-	-	-	-	11,240	[illegible]	1	2,190	1	-	-
Do	.do	7- by 3-inch (W)	22	T	14.9	41.3	50.4	8.3	1.6	-	-	-	-	11,150	[illegible]	1	2,160	1	-	-
Do	.do	1-1/4- by 1/4-inch (AC)	20	T	14.1	41.0	48.9	10.1	1.7	-	-	-	-	11,060	12,970	1	2,190	1	-	-
Do	.do	1-1/4-inch by 10-mesh (W and AC) (3- by 1-1/4-inch, crushed to 1-1/4-inch).	110	T	14.5	40.3	49.0	10.7	1.8	-	-	-	-	10,890	12,720	1	2,180	1	3(1)	58
Williamson County																				
Cambria: Big Muddy	.do	Run-of-mine, crushed to 2-inch	750	T	7.9	37.5	50.7	11.8	3.5	-	-	-	-	11,720	12720	1	2,090	1	3½(1)	57
Energy:																				
Forsyth-Energy	.do	6- by 1-1/4-inch (W)	754	T	8.3	37.5	53.1	9.4	2.8	-	-	-	-	12,050	13,140	1	2,170	1	-	-
Do	.do	1-1/4- by 3/4-inch (W)	156	T	9.5	36.0	54.5	7.5	2.6	-	-	-	-	12,200	13,450	1	2,140	1	-	60
Do	.do	Modified 1-1/4- by 1/4-inch (W) (6- by 1-1/4-inch, crushed to 1-1/4-inch, 50% of 3/4- by 1/4-inch removed).	300	T	7.7	39.3	51.2	9.5	2.9	-	-	-	-	12,160	13,470	1	2,130	1	3½(1)	-
Do	.do	3/4- by 1/4-inch (W)	234	T	9.3	38.6	53.8	7.6	2.5	-	-	-	-	12,210	13,460	1	2,160	1	-	-
Do	.do	1/4-inch by 28-mesh (W)	156	T	11.5	37.4	54.2	8.4	2.4	-	-	-	-	11,770	13,300	1	2,160	1	3½(1)	-
Marion:																				
Orient No. 4	.do	1-1/2-inch by 28-mesh (W)	701	D	7.5	36.4	54.4	9.2	1.4	-	-	-	-	12,250	13,360	2	-	-	-	-
Do	.do	1-inch by 10-mesh (W)	1,484	D	8.9	36.8	55.5	7.7	1.2	-	-	-	-	12,300	13,500	13	2,160	4	5(2) 5½(2)	-
Do	.do	3/4-inch by 0 (W)	3,702	D	7.6	37.3	54.1	8.6	1.6	-	-	-	-	12,260	13,270	5	-	-	-	-
Utility	.do	1-1/4- by 1/4-inch (W)	483	D	6.2	40.1	50.7	9.1	2.7	-	-	-	-	12,400	13,210	2	-	-	-	-
Do	.do	1-1/4-inch by 0 (W)	16,674	D	6.6	40.0	51.1	8.9	2.6	-	-	-	-	12,410	13,240	22	2,240	6	4(3) 4½(2) 5(1)	-
Utility (dock coal)	.do	1-1/4- by 1/4-inch (W)	1,309	D	5.8	39.9	50.9	9.2	2.9	-	-	-	-	12,460	13,240	2	2,140	2	3(1) 4(1)	-
Do	.do	1- by 1/4-inch (W and OT)	5,080	D	7.8	40.0	51.4	8.6	2.6	-	-	-	-	12,240	13,350	15	2,270	5	3(1) 4½(2) 5(1)	-
Will Scarlet	Davis and DeKoven	1-1/2-inch by 10-mesh (W)	2,939	D	5.7	41.8	48.8	9.4	3.6	-	-	-	-	12,700	13,460	7	2,080	1	7(1)	-
Do	.do	1-1/2-inch by 28-mesh (W)	29,062	D	5.5	41.5	49.2	9.3	3.5	-	-	-	-	12,730	13,470	35	2,080	10	6(2) 6½(7) 7(1)	-
Do	.do	1-1/4-inch by 10-mesh (W)	3,699	D	4.3	41.6	49.4	9.0	3.5	-	-	-	-	12,920	13,510	13	-	-	-	-
Do	.do	3/4-inch by 28-mesh (W)	10,013	D	3.9	41.6	49.2	9.2	3.5	-	-	-	-	12,920	13,450	14	2,080	4	5½(2) 6(1) 6½(1)	-
Do	.do	1-inch by 10-mesh (W)	1,400	T	6.1	42.1	49.3	8.6	3.4	-	-	-	-	12,760	13,530	1	2,060	1	-	55
Do	.do	10-mesh by 0 (W)	60	T	4.2	40.6	50.0	9.4	3.6	-	-	-	-	12,890	13,460	1	2,050	1	6½(1)	-
Ziegler (Franklin County):																				
Ziegler No. 3	No. 6	1-1/2-inch by 28-mesh (W)	17,443	D	9.1	37.9	52.7	9.4	2.3	-	-	-	-	11,910	13,110	18	2,200	4	3½(1) 4(2) 5(1)	-
INDIANA																				
Gibson County																				
Princeton: Kings Station	No. V	6- by 3-inch (W)	2,302	D	8.4	39.9	52.7	7.4	2.0	-	-	-	-	12,340	13,470	5	-	-	-	-
Greene County																				
Linton: Airline (32)	.do	1-1/2-inch by 28-mesh (W)	977	D	12.2	40.2	49.1	10.7	2.8	-	-	-	-	11,320	12,530	1	2,190	1	3½(1)	-
Sandborn (Knox County):																				
Hawthorn	.do	Run-of-mine, crushed to 1-1/4-inch (W).	1,800	T	13.0	43.4	46.2	10.4	3.7	-	-	-	-	11,320	[illegible]	1	2,190	1	-	53

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[1] See Explanation of Symbols (p. 3).

[2] Numbers above 1 indicate the number of deliveries averaged.

[3] Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966--Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[1]	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses[1]	Ash-softening temperature, ° F	Number of ash-softening temperatures[1]	Free-swelling index[2]	Hardgrove grindability index[2]
					Moisture, as-received coal	Dry coal								Btu, as-received basis	Btu, dry basis					
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
					INDIANA--Continued															
Greene County--Continued																				
Sandborn (Knox County) (Continued): Hawthorn (Continued)	No. V	Modified Run-of-mine (W), crushed to 1-1/2-inch (Portion of 1-1/2- by 3/8-inch removed).	1,000	T	13.5	43.9	46.5	10.0	3.5	-	-	-	-	11,250	13,010	1	2,260	1	-	-
Do	.do	1-1/2- by 3/8-inch (W)	90	T	13.6	44.3	46.5	9.2	3.4	-	-	-	-	11,390	13,150	1	2,260	1	3(1)	-
Do	.do	3/8-inch by 28-mesh (W)	250	T	15.0	43.1	46.0	10.9	3.8	-	-	-	-	10,920	12,850	1	2,190	1	3(1)	-
Pike County																				
Oakland City (Gibson County): Enos	.do	6- by 3-inch (W)	4,002	D	8.7	42.4	48.1	9.4	3.5	-	-	-	-	11,910	13,050	6	-	-	-	-
Do	.do	1-1/2-inch by 10-mesh (W)	7,830	D	11.0	42.7	48.3	9.0	3.5	-	-	-	-	11,680	13,130	17	2,160	2	4½(2)	-
Do	.do	1-1/2-inch by 28-mesh (W)	11,108	D	10.6	43.0	48.0	9.0	3.9	-	-	-	-	11,750	13,150	15	2,150	3	3½(2) 4(1)	-
Do	.do	1-1/4-inch by 28-mesh (W)	997	D	10.9	43.5	47.9	8.6	3.2	-	-	-	-	11,720	13,150	1	-	-	-	-
Do	.do	1-inch by 10-mesh (W and OT)	23,239	D	10.3	43.4	47.8	8.8	3.3	-	-	-	-	11,830	13,190	28	2,210	7	2½(1) 3½(4) 4(2)	-
Winslow: Blackfoot No. 5	.do	1-1/2-inch by 28-mesh (W)	26,075	D	10.4	44.0	47.3	8.7	3.3	-	-	-	-	11,850	13,230	35	2,140	10	3½(8) 4½(1)	-
Do	.do	1-1/4- by 1/4-inch (W)	17,052	D	10.4	44.3	46.8	8.9	3.4	-	-	-	-	11,820	13,190	30	2,190	6	3½(5) 4(1)	-
Do	.do	1-1/4-inch by 28-mesh (W)	9,743	D	10.5	43.7	47.5	8.8	3.3	-	-	-	-	11,780	13,160	16	2,190	3	3(1) 4(2)	-
Sullivan County																				
Shelburn: Red Ember	No. VI	4-inch lump	18	T	11.7	43.8	47.9	8.3	3.7	-	-	-	-	11,730	13,280	1	2,030	1	-	-
Do	.do	4- by 1-1/4-inch	40	T	13.1	40.9	45.3	13.8	3.1	-	-	-	-	10,800	12,430	1	2,190	1	-	-
Do	.do	1-1/4- by 1/4-inch	22	T	13.2	39.8	44.3	15.9	3.1	-	-	-	-	10,470	12,060	1	2,150	1	-	54
Do	.do	1/4-inch by 0	18	T	13.0	37.7	42.3	20.0	3.1	-	-	-	-	9,850	11,320	1	2,180	1	3(1)	-
Vigo County																				
Riley: Chieftain No. 20	No. VII	1-1/4-inch by 28-mesh (W)	9,892	D	17.0	40.4	49.2	10.4	1.3	-	-	-	-	10,730	12,920	16	2,190	1	3½(1)	-
Terre Haute: Mt. Pleasant	No. V	1-1/4- by 1/4-inch (W)	506	D	10.9	45.3	45.0	9.7	3.8	-	-	-	-	11,660	13,090	3	2,050	2	3(1)	-
					IOWA															
Marion County																				
Knoxville: Beard		1-1/4-inch by 0	13,308	D	17.2	42.3	41.8	15.9	7.4	-	-	-	-	9,600	11,590	23	2,020	6	2(1)	-
					KANSAS															
Cherokee County																				
Hallowell: P and M No. 19		1-1/4- by 1/4-inch (W)	1,964	D	4.2	39.0	51.4	9.6	3.4	-	-	-	-	12,950	13,530	3	2,000	2	-	-
Do		3/4-inch by 28-mesh (W)	4,008	D	5.0	39.5	49.6	10.9	3.4	-	-	-	-	12,650	13,310	6	1,990	3	-	-

Do		1-1/2-inch by 0 (W)	69,133	D	4.2	39.9	48.9	11.2	3.6	-	-	-	-	12,670	13,230	73	1,990	11	9½(1)	-
Do		1-1/4-inch by 0 (W)	717	D	6.4	41.1	49.7	9.2	3.2	-	-	-	-	12,750	13,630	2	2,000	1	-	-
Crawford County																				
Mulberry: Clemens No. 22	Weir-Pittsburg	..do	4,660	D	5.4	36.2	53.2	10.6	4.1	-	-	-	-	12,680	13,410	6	2,020	1	-	-
KENTUCKY (East)																				
Bell County																				
Balkan:																				
Brownies Creek No. 1	Mason	Run-of-mine, crushed to 2-inch	[illegible]	T	2.7	37.9	53.4	8.7	2.1	5.2	76.7	2.1	5.2	13,410	13,790	1	2,440	1	8(1)	59
Chenoa:																				
Davisburg	.do	3-inch lump	[illegible]	T	3.2	38.7	59.7	1.6	.7	-	-	-	-	14,360	14,930	1	2,300	1	-	49
Do	.do	3-inch by 0	[illegible]	T	5.3	36.5	59.6	3.9	.8	-	-	-	-	13,540	14,330	1	2,280	1	4(1)	-
Kettle Island:																				
Adventure No. 1	High Splint (Bottom Bench).	7- by 2-inch	268	D	3.7	38.7	55.3	6.0	.9	-	-	-	-	13,480	14,000	1	-	-	-	-
Do	.do	7- by 3-inch	2,728	D	3.4	38.6	55.6	5.8	.7	-	-	-	-	13,560	14,030	10	-	-	-	-
Do	.do	5- by 2-inch	[illegible]	D	3.4	38.1	53.8	8.1	.8	-	-	-	-	13,190	13,660	4	-	-	-	-
Do	.do	1-1/4- by 1/4-inch	5,592	D	4.0	38.5	54.3	7.2	.9	-	-	-	-	13,250	13,800	12	2,840	3	4(2) 5½(1)	-
Do	.do	1-1/2-inch by 0	4,253	D	4.2	36.9	54.9	8.2	1.0	-	-	-	-	12,970	13,540	6	2,810	3	4(1) 4½(2)	-
Do	.do	1-1/4-inch by 0	59,322	D	5.4	37.1	54.8	8.1	1.0	-	-	-	-	12,820	13,560	75	2,670	25	1½(1) 2½(3) 3(5) 3½(6) 4(5) 4½(1) 5½(2) 6(3)	-
Adventure No. 3	Low Splint (Bottom Bench).	Run-of-mine, crushed	432	D	5.3	36.0	55.5	8.5	1.0	-	-	-	-	12,790	13,510	1	-	-	-	-
Do	.do	1-1/4- by 1/4-inch	4,344	D	3.9	38.0	54.9	7.1	.9	-	-	-	-	13,230	13,820	10	2,820	9	4½(1) 5½(3)	-
Do	.do	1- by 1/4-inch	6,359	D	3.9	37.9	54.2	7.9	.9	-	-	-	-	13,180	13,720	15	2,830	4	5(1) 5½(1) 6(1) 6½(1)	-
Do	.do	1-1/2-inch by 0	233	D	6.4	36.4	54.8	8.8	1.0	-	-	-	-	12,640	13,500	1	-	-	-	-
Adventure No. 5	Low Splint (Top Bench)	Run-of-mine, crushed	57,392	D	5.9	35.9	52.7	11.4	1.0	-	-	-	-	12,170	12,930	50	2,840	1	5(1)	-
Do	.do	1-1/4- by 1/4-inch	5,134	D	4.2	38.4	54.3	7.3	.9	-	-	-	-	13,200	13,750	10	2,850	5	4½(2) 5(3)	-
Middlesboro:																				
Amru No. 2	Hance (Bottom Bench)	Run-of-mine, crushed to 3-inch	310	T	3.4	34.7	51.2	14.1	.9	-	-	-	-	12,330	12,760	1	2,390	1	5½(1)	48
Do	Hance (Two Top Benches).	Run-of-mine, crushed to 2-inch	450	T	4.6	35.1	54.6	10.3	1.1	-	-	-	-	12,810	13,430	1	2,680	1	7½(1)	49
Pinnacle		3-inch lump	50	T	2.2	39.6	55.5	4.9	.8	-	-	-	-	14,000	14,320	1	2,910+	1	-	-
Do		3-inch by 0	130	T	2.6	35.5	49.2	15.3	.9	-	-	-	-	12,350	12,680	1	2,910+	1	4½(1)	40
Roaring Fork	Mason	1-1/4- by 1/4-inch (Run-of-mine, crushed to 1-1/4-inch).	55	T	2.3	39.3	54.3	6.4	1.7	5.4	78.4	2.1	6.0	13,790	14,110	1	2,300	1	-	55
Do	.do	1/4-inch by 0	25	T	2.5	36.9	52.6	10.5	1.9	-	-	-	-	13,110	13,450	1	2,550	1	7(1)	-
Pineville: Bell Hi	.do	Run-of-mine, crushed to 2-inch	250	T	2.4	39.2	51.1	9.7	2.6	5.2	74.9	2.2	5.4	13,290	13,620	1	2,380	1	7(1)	-
Carter County																				
Hitchins:																				
Moore Branch No. 6	Millers Creek	3-inch lump	20	T	6.9	42.0	55.0	3.0	1.1	5.4	79.6	1.7	9.2	13,220	14,200	1	2,670	1	-	-
Do	.do	1-1/2- by 1-inch, crushed to 3/4-inch (3-inch by 0, crushed to 1-1/2-inch).	10	T	6.7	40.7	54.6	4.7	1.2	-	-	-	-	12,960	[illegible]	1	2,740	1	-	-
Do	.do	1- by 1/4-inch	10	T	6.7	39.4	52.8	7.8	.9	-	-	-	-	12,530	13,430	1	2,910+	1	-	-
Do	.do	1/4-inch by 0	10	T	8.6	35.7	50.7	13.6	.9	-	-	-	-	11,380	12,450	1	2,910+	1	2(1)	-
Willard:																				
Lost Creek	Hazard No. 7	2- by 7/8-inch (Run-of-mine, crushed to 2-inch).	15	T	8.6	40.0	53.4	6.6	.7	5.1	76.1	1.5	10.0	12,310	13,470	1	2,910+	1	-	48
Do	.do	7/8-inch by 0	10	T	9.8	36.6	52.5	10.9	1.0	-	-	-	-	11,530	12,750	1	[illegible]	1	[illegible]	-
Do	.do	Run-of-mine, crushed	[illegible]	D	9.0	36.9	52.9	10.2	1.1	-	-	-	-	11,650	[illegible]	12	-	-	-	-

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966–Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[1]	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses[2]	Ash-softening temperature, ° F	Number of ash-softening temperatures[2]	Free-swelling index[2]	Hardgrove grindability index[2]
					Moisture, as-received coal	Dry coal														
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
			KENTUCKY–Continued (East)–Continued																	
Clay County																				
Manchester:																				
Becky Ann Tipple	Horse Creek	8-inch lump	30	T	3.8	38.5	57.6	3.9	.7	-	-	-	-	13,980	14,530	1	2,910+	1	-	44
Do	do	5- by 4-inch	30	T	3.8	38.1	56.8	5.1	.6	-	-	-	-	13,720	14,260	1	2,910+	1	-	-
Do	do	4-inch by 0, crushed to 1-3/4-inch	95	T	4.3	36.8	58.1	5.1	.8	-	-	-	-	13,220	13,810	1	2,910+	1	5(1)	-
Red Glow Tipple	Hazard No. 4 and Horse Creek.	8-inch lump	15	T	3.4	41.7	52.7	5.6	2.1	-	-	-	-	13,660	14,140	1	2,140	1	-	-
Do	do	8- by 4-inch	50	T	3.4	42.6	52.9	4.5	2.0	-	-	-	-	13,850	14,340	1	2,110	1	-	44
Do	do	4-inch by 0, crushed to 2-inch	190	T	4.0	40.4	52.4	7.2	2.2	-	-	-	-	13,340	13,900	1	2,250	1	4½(1)	-
Estill County																				
Irvine:																				
Irvine prep. plant	Elkhorn No. 3	6- by 4-inch (W)	50	T	2.5	40.4	55.6	4.0	.9	-	-	-	-	14,180	14,540	1	2,540	1	-	41
Do	do	1-1/4- by 3/8-inch (W and OT) (4- by 1-1/4-inch, crushed to 1-1/4-inch).	480	T	3.7	41.0	55.3	3.7	1.2	-	-	-	-	14,070	14,610	1	2,300	1	-	-
Do	do	1- by 3/8-inch (W and OT)	540	T	5.5	41.3	54.9	3.8	1.4	-	-	-	-	13,740	14,540	1	2,270	1	-	-
Do	do	3/8-inch by 0 (W)	600	T	3.4	37.7	52.6	9.7	1.5	-	-	-	-	13,030	13,490	1	2,350	1	6(1)	-
Do	Hazard No. 9	Modified Run-of-mine, crushed to 1-1/4-inch (W and OT) (90% of 3/8-inch by 0 removed).	1,620	T	6.2	39.3	53.0	7.7	1.9	-	-	-	-	12,690	13,530	1	2,600	1	-	-
Do	do	1-1/4- by 3/8-inch (W and OT)	360	T	6.1	39.2	53.3	7.5	1.9	-	-	-	-	12,710	13,540	1	2,760	1	-	-
Do	do	3/8-inch by 0 (W)	660	T	6.6	37.7	53.9	8.4	1.8	-	-	-	-	12,170	13,030	1	2,540	1	2(1)	-
Floyd County																				
Harold: Clark No. 3	Elkhorn Nos. 1, 2 and 3.	Run-of-mine, crushed to 1-1/4-inch	250	T	4.8	36.2	51.2	12.6	1.5	-	-	-	-	12,400	13,030	1	2,500	1	5½(1)	-
Harlan County																				
Alva:																				
Alva	Harlan	6-inch lump	20	T	2.3	40.1	57.3	2.6	.7	-	-	-	-	14,420	14,760	1	2,790	1	-	43
Do	do	6- by 3-inch	60	T	2.6	39.7	57.9	2.4	.7	5.4	82.5	1.8	7.2	14,330	14,710	1	2,790	1	-	-
Do	do	3-inch by 0, crushed to 1-1/2-inch	575	T	2.9	36.2	56.3	7.5	.8	-	-	-	-	13,530	13,930	1	2,670	1	5½(1)	-
Pee	Hance	1-1/4- by 1/4-inch (OT) (Run-of-mine, crushed to 1-1/4-inch).	195	T	2.4	37.4	57.5	5.1	1.0	-	-	-	-	13,970	14,310	1	2,730	1	-	-
Do	do	1/4-inch by 0	140	T	3.1	33.4	54.5	12.1	1.0	-	-	-	-	12,760	13,170	1	2,730	1	7(1)	55
Mike	Kellioka	Run-of-mine, crushed to 2-inch	320	T	5.6	36.6	55.2	8.2	1.3	-	-	-	-	12,590	13,340	1	2,660	1	3(1)	45
Coalgood: Kenmack Tipple	Harlan, Creech and Low Splint	Run-of-mine, crushed to 3-inch	820	T	5.7	36.3	55.6	8.1	1.0	-	-	-	-	12,700	13,470	1	2,780	1	3½(1)	46
Evarts:																				
Hi-Lo	Low Splint and No. 9	6-inch lump (W)	30	T	3.8	40.2	55.2	4.6	.7	5.3	79.7	1.6	8.1	13,620	14,160	1	2,470	1	-	-
Do	do	6- by 3-inch (W)	60	T	3.3	40.0	55.0	5.0	.7	-	-	-	-	13,650	14,190	1	2,650	1	-	-
Do	do	3- by 1-1/4-inch (W)	50	T	4.0	40.0	54.6	5.4	.8	-	-	-	-	13,470	14,030	1	2,760	1	-	40
Do	do	1-1/4- by 1/4-inch (W)	140	T	4.5	39.6	53.9	6.5	1.0	-	-	-	-	13,210	13,830	1	2,760	1	-	-
Do	do	1/4-inch by 0 (W)	125	T	7.2	37.9	55.1	7.0	1.2	-	-	-	-	12,740	13,730	1	2,570	1	4(1)	-
Yocum Creek Tipple	Darby	8-inch lump	20	T	2.9	39.4	58.2	2.4	.5	-	-	-	-	14,250	14,680	1	2,300	1	-	-
Do	do	8- by 4-inch	45	T	2.9	39.3	58.8	1.9	.5	-	-	-	-	14,300	14,730	1	2,300	1	-	44
Do	do	3/4- by 1/4-inch (OT) (4- by 3/4-inch, crushed to 3/4-inch).	205	T	3.0	39.5	57.4	3.1	.6	-	-	-	-	14,190	14,630	1	2,270	1	-	-
Do	do	1/4-inch by 0	140	T	3.8	36.4	59.5	4.1	.7	-	-	-	-	13,820	14,370	1	2,250	1	4½(1)	-
Highsplint:																				
Seagraves No. 5	do	6-inch lump (W)	20	T	3.1	40.6	55.9	3.5	.7	-	-	-	-	14,150	14,600	1	2,730	1	-	35
Do	do	6- by 3-inch (W)	45	T	2.8	40.3	56.7	3.0	.7	-	-	-	-	14,290	14,700	1	2,790	1	-	-
Do	do	7/8- by 1/4-inch (W and OT) (3- by 7/8-inch, crushed to 7/8-inch).	200	T	3.6	39.4	57.7	2.9	.8	5.4	82.0	1.6	7.3	14,090	14,620	1	2,480	1	-	-

Do.	.do.	1/4-inch by 0 (W)	170	T	5.3	36.0	56.7	7.3	1.0	-	-	-	-	13,120	13,850	1	2,440	1	6(1)	-
Knox County																				
Barbourville:																				
Richland prep. plant	Blue Gem	7/8- by 1/4-inch (W and OT) (Run-of-mine, crushed to 7/8-inch).	210	T	7.0	41.3	56.0	2.7	1.2	-	-	-	-	13,610	14,630	1	2,090	1	-	-
Do.	.do.	1/4-inch by 0	125	T	8.3	36.9	57.2	5.9	1.2	-	-	-	-	12,940	14,110	1	2,200	1	5(1)	-
Laurel County																				
London:																				
London Tipple	Horse Creek	7-inch lump	10	T	3.2	43.2	51.3	5.5	3.3	-	-	-	-	13,730	14,180	1	2,280	1	-	-
Do.	.do.	7- by 3-inch	15	T	3.2	42.3	51.4	6.3	3.7	-	-	-	-	13,550	14,000	1	2,110	1	-	47
Do.	.do.	1- by 3/8-inch (OT)	15	T	4.2	42.1	50.9	7.0	3.9	-	-	-	-	13,360	13,950	1	2,090	1	4(1)	-
Do.	.do.	Modified 3-inch by 0, crushed to 2-inch (50% of 1- by 3/8-inch removed).	50	T	5.8	41.3	50.6	8.1	4.5	-	-	-	-	12,900	13,690	1	2,130	1	-	-
Lee County																				
Beattyville:																				
Pacemaker	Hazard No. 4	4-inch lump	10	T	5.0	44.2	52.5	3.3	1.3	5.6	79.7	1.7	8.4	13,780	14,500	1	2,250	1	-	-
Do.	.do.	4- by 3-inch	10	T	4.9	43.0	51.4	5.6	2.3	-	-	-	-	13,360	14,050	1	2,060	1	-	-
Do.	.do.	2- by 1/4-inch	10	T	5.8	40.9	50.5	8.6	2.2	-	-	-	-	12,750	13,540	1	2,310	1	-	-
Do.	.do.	3/4- by 1/4-inch (3-inch by 0, crushed to 3/4-inch).	20	T	5.6	40.6	49.0	10.4	2.7	-	-	-	-	12,540	13,280	1	2,200	1	-	-
Do.	.do.	1/4-inch by 0	8	T	10.0	37.0	48.9	14.1	2.0	-	-	-	-	11,310	12,570	1	2,500	1	3½(1)	-
Letcher County																				
Cumberland (Harlan County):																				
Scotia	Imboden	1-1/4- by 1/4-inch (W)	27,339	D	2.8	36.4	57.9	5.7	.9	-	-	-	-	13,910	14,310	56	2,910+	15	6(1) 7(5) 7½(8) 8(1)	-
Do.	.do.	1-1/2-inch by 0 (W)	738	D	2.7	36.7	58.3	5.0	.8	-	-	-	-	14,060	14,460	2	2,910+	1	7½(1)	-
Do.	.do.	1-1/4-inch by 0 (W)	1,741	D	3.6	36.5	57.9	5.6	.8	-	-	-	-	13,780	14,300	4	-	-	-	-
Do.	.do.	3/4-inch by 0 (W)	118	D	9.5	34.4	59.9	5.7	1.0	-	-	-	-	12,910	14,270	2	2,910+	2	8(2)	-
Premium: Highland Tipple	Amburgy	Run-of-mine, crushed to 2-inch	270	T	2.8	35.4	46.2	18.4	3.6	-	-	-	-	11,730	12,070	1	2,430	1	6½(1)	-
Whitesburg:																				
Lorraine Tipple	Elkhorn No. 3 and Whitesburg.	Modified Run-of-mine, crushed to 2-inch (50% of 1-1/4- by 3/8-inch removed).	210	T	5.7	35.5	55.7	8.8	1.5	-	-	-	-	12,660	13,420	1	2,640	1	-	-
Do.	.do.	1-1/4- by 3/8-inch	50	T	5.3	38.5	53.4	8.1	1.4	-	-	-	-	12,740	13,450	1	2,660	1	5(1)	44
Mayking Tipple	Elkhorn No. 3 and Elkhorn Rider.	Run-of-mine, crushed to 1-1/2-inch	270	T	5.4	36.1	56.0	7.9	1.1	-	-	-	-	12,880	13,610	1	2,600	1	4(1)	44
Sapphire	Elkhorn No. 3	6-inch lump	60	T	2.4	40.6	55.6	3.8	1.1	5.5	81.5	1.6	6.5	14,170	14,520	1	2,430	1	-	39
Do.	.do.	6- by 4-inch (W)	60	T	2.5	41.8	54.8	3.4	1.3	-	-	-	-	14,200	14,560	1	2,160	1	-	-
Do.	.do.	1- by 3/8-inch (W and OT) (4- by 1-inch, crushed to 1-inch).	210	T	3.3	41.3	54.8	3.9	1.5	-	-	-	-	13,990	14,470	1	2,180	1	-	-
Do.	.do.	3/8-inch by 0	130	T	4.9	35.7	52.9	11.4	1.7	-	-	-	-	12,550	13,200	1	2,300	1	6(1)	-
Tim Tipple	Whitesburg	Run-of-mine, crushed to 1-1/4-inch	115	T	2.8	37.0	53.8	9.2	1.6	-	-	-	-	13,210	13,590	1	2,670	1	4½(1)	41
Walls Tipple	.do.	..do.	370	T	4.4	37.7	57.3	5.0	1.0	-	-	-	-	13,440	14,060	1	2,640	1	3½(1)	43
McCreary County																				
Stearns:																				
Stearns Nos. 21 and 22	No. 2	Run-of-mine, crushed to 3-inch	450	T	3.7	40.2	47.4	12.4	4.1	-	-	-	-	12,460	12,940	1	2,090	1	4½(1)	46
Perry County																				
Bulan:																				
Indian Head Tipple	Hazard Nos. 5-A and 7.	6-inch lump	50	T	4.3	38.3	55.6	6.1	.6	-	-	-	-	13,350	13,950	1	2,910+	1	-	38
Do.	.do.	6-inch by 0, crushed to 3-inch	215	T	5.1	36.6	53.8	9.6	.7	-	-	-	-	12,750	13,440	1	2,910+	1	4(1)	-
Jakes Fork Tipple	Hazard No. 7	8-inch lump	40	T	3.7	38.6	54.4	7.0	.6	-	-	-	-	13,400	13,920	1	2,910+	1	-	37
Do.	.do.	8-inch by 0, crushed to 2-inch	275	T	4.5	36.3	55.3	8.4	.6	-	-	-	-	13,010	13,620	1	2,910+	1	5(1)	-
Combs:																				
Big Creek	.do.	6-inch lump	15	T	4.0	38.5	54.4	7.1	.6	-	-	-	-	13,350	13,910	1	2,910+	1	-	36
Do.	.do.	6-inch by 0, crushed to 1-1/2-inch	85	T	4.6	36.1	54.9	9.0	.6	-	-	-	-	12,940	13,560	1	2,910+	1	4½(1)	-

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[1] See Explanation of Symbols (p. 5).

[2] Numbers above 1 indicate the number of deliveries averaged.

[3] Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[2]	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses[2]	Ash-softening temperature, °F	Number of ash-softening temperatures[3]	Free-swelling index[2]	Hardgrove grindability index[2]
					Moisture, as-received coal	Dry coal								Btu, as-received basis	Btu, dry basis					
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
KENTUCKY—Continued (East)—Continued																				
Perry County--Continued																				
Hazard:																				
Lennut Tipple	Hazard Nos. 5-A and 7	6-inch lump	70	T	3.8	39.8	53.6	6.6	.8	-	-	-	-	13,370	13,900	1	2,910+	1	-	38
Do.	.do.	6-inch by 0, crushed to 1-1/4-inch	250	T	4.5	36.7	52.5	10.8	1.0	-	-	-	-	12,600	13,190	1	2,910+	1	4(1)	-
Leatherwood:																				
Leatherwood No. 1	Leatherwood	6- by 3-inch (W)	7,316	D	2.8	40.0	55.4	4.6	.6	-	-	-	-	13,910	14,310	3	-	-	-	-
Do.	.do.	5- by 3-inch (W)	1,924	D	3.0	39.9	55.9	4.2	.5	-	-	-	-	13,920	14,360	2	-	-	-	-
Scuddy:																				
Scuddy Tipple	Hazard Nos. 4 and 7	6-inch lump	40	T	3.4	39.1	56.7	4.2	.6	-	-	-	-	13,920	14,410	1	2,910+	1	-	41
Do.	.do.	6- by 4-inch	35	T	3.4	39.0	56.7	4.3	.6	-	-	-	-	13,840	14,330	1	2,910+	1	-	-
Do.	.do.	4-inch by 0, crushed to 2-inch	240	T	4.4	36.0	55.2	8.8	.8	-	-	-	-	13,040	13,640	1	2,910+	1	5½(1)	-
Stoker Tipple	Hazard No. 4	6-inch lump	25	T	2.8	39.7	58.1	2.2	.6	-	-	-	-	14,380	14,790	1	2,590	1	-	-
Do.	.do.	6- by 4-inch	50	T	3.0	40.2	57.4	2.4	.7	-	-	-	-	14,320	14,760	1	2,540	1	-	45
Do.	.do.	4-inch by 0, crushed to 1-1/4-inch (OT).	350	T	3.1	38.2	57.0	4.8	.8	-	-	-	-	13,880	14,320	1	2,820	1	5(1)	-
Vicco:																				
Montoco Tipple	Hazard No. 9	6-inch lump	50	T	3.5	41.3	52.4	6.3	2.1	-	-	-	-	13,460	13,950	1	2,570	1	-	39
Do.	.do.	6-inch by 0, crushed to 2-inch	250	T	4.4	38.6	52.1	9.3	2.5	-	-	-	-	12,820	13,410	1	2,520	1	5½(1)	-
Pike County																				
Biggs:																				
Kentland No. 1	Lower Elkhorn	Run-of-mine, crushed to 2-inch	1,1[illegible]	T	2.7	31.8	55.9	12.3	.6	-	-	-	-	13,030	13,390	1	2,890	1	8(1)	50
Do.	.do.	6- by 1-1/4-inch (W) (crushed to 1-1/4-inch).	17[illegible]	T	3.3	34.9	59.9	5.2	.6	-	-	-	-	14,160	14,640	1	2,910+	1	-	-
Do.	.do.	1-1/4- by 1/4-inch (W)	515	T	3.5	35.2	59.8	5.0	.6	-	-	-	-	14,060	14,570	1	2,910+	1	-	-
Do.	.do.	Middlings, crushed to 1-1/4-inch (W).	240	T	4.5	29.2	49.9	20.9	.5	-	-	-	-	11,450	11,990	1	2,910+	1	-	-
Do.	.do.	1/4-inch by 0 (W)	390	T	3.6	33.3	61.8	4.9	.6	5.1	82.5	1.5	5.4	14,070	14,600	1	2,910+	1	8½(1)	-
Spruce Fork	.do.	Run-of-mine, crushed to 2-inch	830	T	2.7	31.4	57.0	11.6	.6	-	-	-	-	13,160	13,550	1	2,870	1	9(1)	56
Elkhorn City:																				
Kentucky Elkhorn Tipple		Run-of-mine, crushed to 2-1/2-inch	650	T	2.7	33.0	57.9	9.1	1.1	-	-	-	-	13,590	13,970	1	2,710	1	8(1)	56
Sadie Tipple	Elkhorn No. 1	Run-of-mine, crushed to 2-inch	430	T	3.5	30.5	55.9	13.6	.7	-	-	-	-	12,650	13,110	1	2,710	1	8(1)	58
Freeburn: Vulcan Tipple	Cedar Grove and Pond Creek.	Run-of-mine, crushed to 1-1/4-inch	275	T	4.7	33.9	59.4	6.7	.9	-	-	-	-	13,480	14,150	1	2,780	1	7(1)	57
Leckieville:																				
Osborne Tipple	Cedar Grove	1-1/4- by 1/4-inch (W) (Run-of-mine, crushed to 1-1/4-inch).	265	T	3.3	42.6	52.4	5.0	1.6	-	-	-	-	13,880	14,350	1	2,360	1	-	54
Do.	.do.	1/4-inch by 0	140	T	5.3	34.2	46.6	19.2	1.9	-	-	-	-	11,370	12,010	1	2,620	1	5½(1)	-
Lookout:																				
Henry Clay Tipple	Elkhorn No. 1	1-1/4- by 3/8-inch (Run-of-mine, crushed to 1-1/4-inch).	170	T	2.8	33.3	55.6	11.1	.9	-	-	-	-	13,050	13,430	1	2,680	1	-	-
Do.	.do.	3/8-inch by 0	150	T	4.7	32.1	55.8	12.1	.8	-	-	-	-	12,650	13,270	1	2,680	1	7½(1)	56
Lookout Tipple	Elkhorn Nos. 1, 2 and 3.	Run-of-mine, crushed to 2-inch	280	T	2.8	32.0	57.4	10.6	.7	-	-	-	-	13,250	13,630	1	2,760	1	8(1)	53
McCarr:																				
Kentucky Alma Tipple	Alma	Run-of-mine, crushed to 2-inch (metallurgical coal).	200	T	3.8	35.1	59.4	5.5	.6	-	-	-	-	14,000	14,550	1	2,910+	1	7(1)	46
Do.	.do.	Run-of-mine, crushed to 2-inch (steam coal).	155	T	4.4	33.5	58.1	8.4	.6	-	-	-	-	13,150	13,760	1	2,910+	1	4(1)	46
Little Lump	Pond Creek	Run-of-mine, crushed to 2-inch	180	T	2.5	31.9	54.9	13.2	.8	4.8	73.9	1.3	6.0	12,820	13,150	1	2,870	1	8(1)	52
Millard: Clark No. 1	Elkhorn No. 3	..do.	160	T	3.0	38.8	53.7	7.5	1.5	5.2	77.8	1.5	6.5	13,580	14,000	1	2,450	1	6(1)	44
Mouthcard: Clintwood Tipple	Clintwood, Hagy, Eagle, and Lower Elkhorn.	Run-of-mine, crushed to 2-inch (2- by 3/8-inch (W)).	500	T	3.3	32.7	58.6	8.7	2.0	-	-	-	-	13,650	14,120	1	2,590	1	6½(1)	-
Phelps:																				
Caney Branch	Pond Creek	Run-of-mine, crushed to 2-inch	260	T	3.6	31.3	55.0	13.7	.6	4.7	74.1	1.4	5.5	12,660	13,130	1	2,910+	1	9(1)	53
D. and J.	Cedar Grove	..do.	180	T	2.0	36.3	53.6	10.1	2.4	5.0	75.9	1.3	5.3	13,340	13,610	1	2,550	1	6(1)	49

Kencar No. 1	Pond Creek	6- by 1-1/4-inch (W) (crushed to 1-1/4-inch).	365	T	2.9	35.6	60.6	3.8	.6	-	-	-	-	14,410	14,840	1	2,910+	1	-	-
Do	.do	1-1/4- by 1/4-inch (W)	455	T	4.5	34.5	62.0	3.5	.6	5.3	83.5	1.5	5.6	14,180	14,850	1	2,910+	1	8½(1)	-
Pikeville:																				
Danna Sue	Elkhorn No. 2	Run-of-mine, crushed to 2-inch	275	T	4.1	38.0	54.3	7.7	1.0	5.1	77.5	1.0	7.7	13,230	13,800	1	2,910+	1	4½(1)	46
F. and F.	Elkhorn No. 3 (Upper Split).	Run-of-mine, crushed to 1-1/4-inch	150	T	5.8	33.1	55.6	11.3	.6	-	-	-	-	12,320	13,080	1	2,910+	1	2½(1)	-
Island Creek Dock	Elkhorn No. 3	Run-of-mine, crushed to 2-inch	170	T	5.2	33.7	48.9	17.4	1.0	4.6	68.7	1.2	7.1	11,560	12,190	1	2,600	1	4(1)	53
Regina:																				
Southern Elkhorn Tipple	Elkhorn Nos. 1 and 2	..do	410	T	4.3	32.1	51.4	16.5	1.5	-	-	-	-	11,960	12,500	1	2,730	1	8(1)	57
Virgie:																				
Kentucky No. 1 Tipple	Elkhorn No. 2	..do	400	T	2.9	35.5	53.6	10.9	1.4	-	-	-	-	12,970	13,360	1	2,680	1	6½(1)	46
Pulaski County																				
Somerset:																				
Ikerd and Bandy No. 1	No. 3	..do	300	T	7.1	35.3	55.1	9.6	1.6	-	-	-	-	12,250	13,190	1	2,790	1	3½(1)	43
Whitley County																				
Corbin: Woodbine Tipple	Jellico	..do	110	T	4.5	36.2	56.9	6.9	1.1	-	-	-	-	13,240	13,860	1	2,770	1	5½(1)	50
Williamsburg: Savoy Tipple	.do	..do	135	T	4.4	36.7	53.5	9.8	1.6	-	-	-	-	12,800	13,390	1	2,290	1	5(1)	47

KENTUCKY
(West)

Hopkins County																				
Madisonville:																				
Colonial	No. 11	3/4-inch by 28-mesh (W)	4,152	D	7.7	42.9	50.2	6.9	3.2	-	-	-	-	12,500	13,540	19	2,130	3	3½(2) 4(1)	-
Fies	.do	1-1/2-inch by 28-mesh (W)	4,402	D	7.2	43.0	50.4	6.6	3.0	-	-	-	-	12,600	13,580	10	2,070	4	3½(3) 4(1)	-
Do	.do	1-1/4- by 1/4-inch (W)	1,503	D	8.4	42.6	50.8	6.6	2.9	-	-	-	-	12,410	13,550	5	2,140	3	3½(1) 4(2)	-
Do	.do	1-1/2-inch by 0 (W)	1,580	D	7.1	43.4	50.4	6.2	3.1	-	-	-	-	12,580	13,650	3	2,140	2	3(1) 3½(1)	-
Fies (dock coal)	.do	1-1/4- by 1/4-inch (W)	455	D	8.0	43.1	50.5	6.4	3.0	-	-	-	-	12,520	13,610	7	2,120	3	3½(3)	-
Oriole	.do	..do	1,652	D	8.3	42.9	50.4	6.7	3.2	-	-	-	-	12,480	13,610	8	2,090	4	3½(1) 4(2) 4½(1)	-
Saint Charles:																				
Buffalo Creek	No. 6	1-1/4- by 1-inch (W) (Run-of-mine, crushed to 1-1/4-inch).	150	T	9.6	41.8	54.4	3.8	1.9	-	-	-	-	12,730	14,080	1	2,100	1	-	51
Do	.do	1- by 1/2-inch (W)	450	T	10.3	41.7	54.5	3.8	1.9	-	-	-	-	12,620	14,070	1	2,060	1	-	-
Do	.do	1/2- by 1/4-inch (W)	200	T	12.0	41.6	54.1	4.3	2.0	-	-	-	-	12,290	13,970	1	2,080	1	-	-
Do	.do	1/4-inch by 28-mesh (W)	200	T	13.5	40.5	55.8	3.7	1.8	-	-	-	-	12,190	14,090	1	2,080	1	3½(1)	-
Muhlenberg County																				
Central City:																				
Crescent (Brier Creek)	No. 11	1-1/2-inch by 28-mesh (W)	1,761	D	9.6	43.0	49.9	7.1	3.1	-	-	-	-	12,230	13,520	3	-	-	-	-
Do	.do	3/4-inch by 28-mesh (W)	225	D	6.9	43.2	49.5	7.3	3.1	-	-	-	-	12,550	13,430	1	-	-	-	-
Greenville:																				
Canney Creek	.do	7- by 2-inch (W)	104	D	7.7	42.6	50.0	7.3	3.5	-	-	-	-	12,300	13,330	2	-	-	-	-
Do	.do	5- by 2-inch (W)	14,023	D	7.2	43.1	49.9	7.0	3.6	-	-	-	-	12,500	13,480	17	-	-	-	-
Do	.do	1-1/4- by 1/4-inch (W)	30,842	D	7.5	43.7	49.6	6.7	3.5	-	-	-	-	12,490	13,490	34	2,150	9	3(1) 3½(4) 4(2) 4½(2)	-
Do	.do	1-1/4-inch by 28-mesh (W)	5,372	D	8.5	43.8	49.5	6.7	3.4	-	-	-	-	12,330	13,480	12	2,120	4	3½(2) 4(1) 5(1)	-
Do	.do	1-1/2-inch by 0 (W)	5,506	D	9.4	43.9	49.2	6.9	3.4	-	-	-	-	12,190	13,460	9	2,120	3	3½(2)	-
Wright	.do	3- by 3/4-inch (W)	207	D	7.9	42.3	48.9	8.8	3.5	-	-	-	-	12,130	13,170	1	-	-	-	-
Madisonville (Hopkins County):																				
Vogue	.do	7- by 2-inch (W)	22,580	D	7.4	44.8	49.4	5.9	3.1	-	-	-	-	12,650	13,660	24	-	-	-	-
Do	.do	1-1/4-inch by 28-mesh (W and OT)	203	D	10.4	45.4	48.6	6.0	3.0	-	-	-	-	12,240	13,660	1	-	-	-	-
Vogue (dock coal)	.do	1-1/4- by 1/4-inch (W)	401	D	7.4	43.6	50.0	6.4	3.1	-	-	-	-	12,620	13,630	1	-	-	-	-

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1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses	Ash-softening temperature, ° F	Number of ash-softening temperatures	Free-swelling index	Hardgrove grindability index
					Moisture, as-received coal	Dry coal														
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as-received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
KENTUCKY -Continued (West)—Continued																				
Union County																				
Sturgis:																				
DeKoven Tipple	Nos. 6 and 9	3- by 1-1/2-inch (W) (Run-of-mine, crushed to 3-inch).	1,300	T	3.2	40.7	50.5	8.8	2.9	-	-	-	-	13,140	13,570	1	2,120	1	-	-
Do	.do	1-1/2-inch by 0	2,930	T	4.5	37.4	49.2	13.4	3.7	-	-	-	-	12,250	12,830	1	2,080	1	7(1)	58
Wheatcroft (Webster County):																				
Black Tam	No. 9	Run-of-mine, crushed to 4-inch	1,200	T	4.7	36.6	49.4	14.0	4.4	-	-	-	-	12,080	12,680	1	2,050	1	7(1)	57
MISSOURI																				
Macon County																				
Excello: Bee Veer	Bevier	1-1/4- by 1/4-inch (W)	2,915	D	13.6	45.1	47.2	7.7	4.0	-	-	-	-	11,440	13,250	13	2,030	5	-	-
MONTANA																				
Carbon County																				
Red Lodge:																				
Smokeless and Sootless	No. 2	5-inch lump	28	T	10.9	37.8	56.6	5.6	1.0	5.0	73.0	1.9	13.5	11,360	12,750	1	2,080	1	-	-
Do	.do	5- by 2-inch (W)	18	T	9.3	38.5	53.6	7.9	1.5	-	-	-	-	11,190	12,340	1	2,060	1	-	-
Do	.do	1-1/4- by 3/8-inch (W) (2- by 1-1/4-inch, crushed to 1-1/4-inch).	25	T	10.5	37.6	52.8	9.6	1.8	-	-	-	-	10,920	12,200	1	2,060	1	-	50
Do	.do	3/8-inch by 0 (W)	15	T	18.4	36.5	56.8	6.7	1.3	-	-	-	-	10,240	12,550	1	2,060	1	-	-
Musselshell County																				
Roundup:																				
Nies	Roundup	12-inch lump	3	T	12.4	34.5	54.8	10.7	.4	-	-	-	-	10,700	12,220	1	2,380	1	-	-
Do	.do	12- by 7-inch	6	T	12.0	34.7	55.7	9.6	.4	-	-	-	-	10,930	12,420	1	2,380	1	-	-
Do	.do	7- by 4-inch	8	T	12.4	34.6	57.3	8.1	.4	-	-	-	-	11,030	12,590	1	2,340	1	-	-
Do	.do	4- by 1-1/2-inch	6	T	12.6	35.2	57.0	7.8	.4	-	-	-	-	11,040	12,630	1	2,350	1	-	-
Do	.do	1-1/2- by 1/4-inch	8	T	12.3	34.5	55.9	9.6	.4	-	-	-	-	10,800	12,320	1	2,410	1	-	51
Do	.do	1/4-inch by 0	8	T	12.3	34.7	52.6	12.7	.6	-	-	-	-	10,450	11,920	1	2,390	1	-	-
Square Deal	.do	6-inch lump	8	T	11.8	34.9	54.6	10.5	.4	-	-	-	-	10,770	12,210	1	2,410	1	-	-
Do	.do	6- by 3-inch	10	T	12.2	34.9	56.0	9.1	.4	-	-	-	-	10,930	12,450	1	2,410	1	-	-
Do	.do	3- by 1-1/4-inch	10	T	12.2	34.6	54.7	10.7	.5	-	-	-	-	10,630	12,180	1	2,620	1	-	50
Do	.do	1-1/4- by 1/4-inch (OT)	12	T	12.6	35.9	54.8	9.3	.4	-	-	-	-	10,840	12,400	1	2,410	1	-	-
Do	.do	1/4-inch by 0	10	T	12.8	34.2	55.0	10.8	.7	-	-	-	-	10,570	12,120	1	2,350	1	-	-
Richland County																				
Savage: Savage		Run-of-mine, crushed to 2-1/2-inch	750	T	37.9	40.9	48.9	10.2	.8	-	-	-	-	6,660	10,730	1	2,500	1	-	-
NEW MEXICO																				
McKinley County																				
Gallup:																				
Sundance	Black Diamond	1-1/4-inch lump	50	T	13.3	44.0	48.7	7.3	.7	-	-	-	-	11,380	13,120	1	2,720	1	-	-

Do.	.do.	1-1/4- by 1/4-inch	30	T	13.5	44.4	47.5	8.1	1.0	-	-	-	-	11,210	12,960	1	2,550	1	-	53
Do.	.do.	1/4-inch by 0	15	T	15.9	41.5	44.9	13.6	1.2	-	-	-	-	10,030	11,930	1	2,320	1	1(1)	-
Do.	.do.	1-1/4- by 1/4-inch	3,888	D	10.1	43.9	49.2	6.9	.7	-	-	-	-	11,810	13,140	8	2,330	3	-	-
Do.	.do.	1-1/2-inch by 0 (OT)	1,478	D	12.7	44.0	48.4	7.6	.8	-	-	-	-	11,330	12,980	11	2,560	4	-	-
NORTH DAKOTA																				
Burke County																				
Larson:																				
Baukol Noonan		Run-of-mine, crushed to 8-inch	[illegible],000	T	33.9	33.5	51.3	9.2	.6	-	-	-	-	7,440	11,260	1	2,140	1	-	41
Do.		1-1/2- by 1/4-inch	[illegible],821	D	32.8	40.4	50.0	9.6	.4	-	-	-	-	7,590	11,300	15	2,130	7	-	-
Mercer County																				
Beulah:																				
Beulah		..do.	27,461	D	35.8	40.6	48.6	10.8	.9	-	-	-	-	6,930	10,790	30	2,370	3	-	-
Do.		1-1/2-inch by 0.	5,259	D	35.8	41.1	49.2	9.7	.9	-	-	-	-	7,050	10,950	20	2,470	4	-	-
Hazen: Dakota Star		..do.	67	D	36.3	42.5	47.7	9.8	1.2	-	-	-	-	7,010	11,000	1	-	-	-	-
Zap: Indian Head		1-1/2-inch by 0 (OT)	2,250	D	33.9	42.1	47.8	10.1	.8	-	-	-	-	7,290	11,040	5	2,210	2	-	-
Ward County																				
Velva (McHenry County):																				
Velva		1-1/2- by 1/4-inch	44,753	D	37.9	43.1	50.1	6.8	.3	-	-	-	-	6,900	11,110	63	2,510	12	-	-
OHIO																				
Columbiana County																				
Lisbon:																				
Snead No. 1	Middle Kittanning (No. 6).	Run-of-mine	150	T	5.1	36.7	49.2	14.1	4.4	-	-	-	-	12,020	12,670	1	2,240	1	5½(1)	53
Snead No. 2	Upper Freeport (No. 7)	..do.	75	T	11.6	31.6	53.4	15.0	.5	-	-	-	-	10,510	11,890	1	2,570	1	-	52
Salem: Guilford	Middle Kittanning (No. 6).	..do.	149	T	6.3	38.5	54.0	7.5	2.8	-	-	-	-	12,740	13,600	1	2,000	1	4½(1)	46
Coshocton County																				
Coshocton: Broken Aro	.do.	1-1/2- by 1/4-inch (W)	4,689	D	7.3	45.6	49.0	5.4	2.9	-	-	-	-	12,580	13,570	8	2,110	1	3½(1)	-
Jefferson County																				
East Springfield: Jennie	Lower Kittanning (No. 5).	1-1/4- by 1/4-inch (W)	1,321	D	3.9	41.0	51.3	7.7	2.3	-	-	-	-	13,260	13,800	8	2,260	2	5(1) [illegible]	-
Smithfield: Bufvay No. 1	Pittsburgh (No. 8)	Run-of-mine, crushed to 4-inch	360	T	7.8	36.6	51.0	12.4	2.4	-	-	-	-	11,640	12,630	1	2,110	1	[illegible]	-
Perry County																				
New Lexington:																				
Sidwell No. 2	Middle Kittanning (No. 6).	1-1/4-inch by 0 (W)	25,630	D	9.0	43.7	48.0	8.3	3.1	-	-	-	-	11,920	13,100	46	2,150	11	[illegible]	-
Sunnyhill prep. plant	.do.	1-1/4- by 1/4-inch (W)	16,630	D	7.4	42.3	47.1	10.6	3.0	-	-	-	-	11,890	12,780	23	2,270	8	[illegible]	-
Do.	.do.	1- by 3/8-inch (W)	4,896	D	9.1	41.5	47.6	10.8	2.8	-	-	-	-	11,540	12,690	6	2,240	3	[illegible]	-
Do.	.do.	1-1/4-inch by 0 (W)	20,056	D	7.5	42.4	47.4	10.2	2.9	-	-	-	-	11,850	12,800	25	2,190	8	[illegible]	-
Shawnee: Star	.do.	Run-of-mine, crushed to 1-1/2-inch	100	T	9.6	40.1	48.6	11.3	2.1	-	-	-	-	11,420	12,630	1	[illegible]	1	[illegible]	[illegible]
Somerset: Old Mt. Perry	.do.	Run-of-mine, crushed to 1-inch (W)	420	T	9.6	46.2	47.7	6.1	3.1	-	-	-	-	12,060	13,340	1	2,200	1	[illegible]	[illegible]

1/ See Explanation of Symbols (p. 5).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[2]	Proximate, percent: Moisture, as-received coal	Proximate, percent: Dry coal: Volatile matter	Proximate, percent: Dry coal: Fixed carbon	Proximate, percent: Dry coal: Ash	Ultimate, percent: Dry coal: Sulfur	Ultimate, percent: Dry coal: Hydrogen	Ultimate, percent: Dry coal: Carbon	Ultimate, percent: Dry coal: Nitrogen	Ultimate, percent: Dry coal: Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses[3]	Ash-softening temperature, ° F	Number of ash-softening temperatures[3]	Free-swelling index[3]	Hardgrove grindability index[3]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
OHIO—Continued																				
Tuscarawas County																				
Midvale:																				
Midvale	Middle Kittanning (No. 6).	1-1/2- by 1/4-inch (W)	75	D	5.3	43.4	49.7	6.9	2.4	-	-	-	-	12,930	13,650	1	-	-	-	-
Do	.do	1-1/4- by 1/4-inch (W)	4,294	D	5.2	43.3	50.0	6.7	2.5	-	-	-	-	12,930	13,640	13	2,160	5	3(3) 3½(1) 4½(1)	-
Do	.do	1- by 3/8-inch (W)	9,908	D	5.8	42.7	50.3	7.0	2.5	-	-	-	-	12,810	13,600	14	2,190	4	2½(1) 3(1) 4½(1)	-
Do	.do	7/8- by 3/8-inch (W)	180	D	4.5	43.8	49.9	6.3	2.5	-	-	-	-	13,080	13,700	1	-	-	-	-
OKLAHOMA																				
Craig County																				
Welch:																				
Patch		Run-of-mine, crushed to 2-inch	200	T	3.7	44.4	47.1	8.5	4.4	-	-	-	-	13,010	13,510	1	2,020	1	8(1)	59
Do		..do	65	T	5.2	35.3	49.7	15.0	6.2	-	-	-	-	11,930	12,580	1	1,980	1	8½(1)	63
Haskell County																				
McCurtain: Evans	Hartshorne	Run-of-mine, crushed to 2-inch (W)	400	T	6.6	23.2	71.0	5.8	.8	-	-	-	-	13,710	14,680	1	2,140	1	9(1)	-
Stigler: Garland	Stigler	Run-of-mine, crushed to 4-inch	650	T	3.1	26.2	69.7	4.1	.5	-	-	-	-	14,460	14,920	1	2,070	1	9(1)	95
Le Flore County																				
Poteau:																				
Poteau	Cavanal	2-inch lump	35	T	2.0	21.9	69.1	9.0	3.2	-	-	-	-	13,830	14,110	1	2,370	1	-	-
Do	.do	2-inch by 0	5	T	2.0	21.8	67.3	10.9	3.2	-	-	-	-	13,450	13,720	1	2,370	1	9(1)	111
Rogers County																				
Claremore:																				
Rogers County (Sequoyah)		Modified Run-of-mine, crushed to 1-1/4-inch (1/2-inch by 0 removed).	700	T	7.4	35.5	58.4	6.1	.5	-	-	-	-	12,950	13,980	1	2,340	1	4½(1)	-
Do		6- by 1-1/4-inch	600	T	7.7	35.9	58.4	5.7	.5	-	-	-	-	12,870	13,940	1	2,250	1	-	-
Do		1-1/4- by 1/4-inch	106	D	6.4	34.7	59.7	5.6	.6	-	-	-	-	13,080	13,980	2	-	-	-	-
Do		1-1/4-inch by 0	375	T	8.7	34.4	55.6	10.0	.6	-	-	-	-	12,080	13,230	1	2,230	1	-	66
PENNSYLVANIA (Anthracite)																				
Dauphin County																				
Lykens:																				
Underkoffler		Buckwheat No. 1	912	D	3.3	7.9	77.7	14.4	.6	-	-	-	-	12,550	12,980	2	2,580	2	-	-
Do		Barley	1,487	D	7.1	7.6	77.3	15.1	.6	-	-	-	-	11,950	12,860	10	2,700	4	-	-
Lackawanna County																				
Taylor: Taylor (Moffat)		..do	296	D	8.4	6.7	74.1	19.2	.6	-	-	-	-	11,110	12,130	1	2,880	1	-	-

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Luzerne County																				
Ashley:																				
Huber		Pea	254	D	3.8	5.2	82.5	12.3	.8	-	-	-	-	12,530	13,030	1	2,910+	1	-	-
Do.		Buckwheat No. 1	1,379	D	3.5	5.9	79.5	14.6	.8	-	-	-	-	12,190	12,640	2	2,910+	2	-	-
Do.		Barley	20,451	D	8.0	5.7	83.0	11.3	.7	-	-	-	-	12,140	13,200	22	2,910+	16	-	-
Nanticoke: Loomis		..do.	50	D	9.0	5.8	82.9	11.3	.5	-	-	-	-	11,960	13,140	1	2,910+	1	-	-
Plymouth: Loree-Woodward		Pea	1,803	D	4.0	6.1	83.6	10.3	.7	-	-	-	-	12,950	13,490	5	2,910+	2	-	-
Swoyersville:																				
Harry E		Stove	70	T	4.5	5.2	85.1	9.7	.7	-	-	-	-	12,880	13,490	1	2,910+	1	-	-
Do.		Chestnut	150	T	4.6	5.1	85.8	9.1	.6	-	-	-	-	12,920	13,540	1	2,910+	1	-	-
Do.		Pea	70	T	4.6	5.7	84.9	9.4	.6	-	-	-	-	12,900	13,520	1	2,910+	1	-	-
Do.		Buckwheat No. 1	100	T	3.6	5.7	83.7	10.6	.6	-	-	-	-	12,790	13,270	1	2,910+	1	-	-
Do.		Rice	70	T	3.5	5.7	83.3	11.0	.6	-	-	-	-	12,720	13,180	1	2,910+	1	-	-
Do.		Barley	50	T	3.7	6.2	80.6	13.2	.6	-	-	-	-	12,360	12,840	1	2,910+	1	-	-
Do.		Buckwheat No. 4	50	T	3.7	6.1	80.8	13.1	.6	-	-	-	-	12,310	12,780	1	2,910+	1	-	-
Do.		Buckwheat No. 5	50	T	4.9	8.2	72.4	19.4	.7	-	-	-	-	11,210	11,790	1	2,250	1	-	-
Wilkes-Barre: Dorrance		Barley	5,779	D	9.7	6.2	80.1	13.7	.6	-	-	-	-	11,500	12,730	24	2,910+	13	-	-
Northumberland County																				
Shamokin:																				
Glen Burn		Egg	1,215	D	3.5	6.5	82.5	11.0	.8	-	-	-	-	12,930	13,400	5	2,910+	1	-	-
Do.		Chestnut	634	D	3.5	6.9	82.1	10.9	.8	-	-	-	-	12,970	13,430	4	2,910+	2	-	-
Do.		Pea	1,141	D	2.9	7.2	81.4	11.4	.7	-	-	-	-	13,000	13,390	5	2,910+	2	-	-
Do.		Buckwheat No. 1	767	D	4.6	6.4	82.5	11.1	.7	-	-	-	-	12,700	13,310	9	2,910+	4	-	-
Do.		Barley	22,444	D	6.4	7.7	81.1	11.2	.7	-	-	-	-	12,410	13,260	30	2,910+	11	-	-
North Line		Buckwheat No. 1	84	D	3.6	10.5	77.9	11.6	.8	-	-	-	-	12,570	13,040	1	-	-	-	-
Trevorton:																				
Trevorton		..do.	1,688	D	1.8	9.1	84.7	6.2	.8	-	-	-	-	14,220	14,470	5	2,910+	1	-	-
Do.		Rice	394	D	1.5	8.9	85.0	6.1	.9	-	-	-	-	14,310	14,530	1	-	-	-	-
Do.		Barley	8,751	D	6.0	9.0	82.0	9.0	.8	-	-	-	-	13,130	13,970	11	2,910+	4	-	-
Schuylkill County																				
Donaldson:																				
Donaldson		Pea	759	D	3.4	6.7	80.7	12.6	.6	-	-	-	-	12,730	13,180	6	2,770	3	-	-
Do.		Buckwheat No. 1	597	D	4.5	7.7	78.8	13.5	.5	-	-	-	-	12,500	13,090	1	2,780	1	-	-
Do.		Barley	7,253	D	8.9	6.8	80.0	13.2	.5	-	-	-	-	11,920	13,080	26	2,800	13	-	-
Minersville:																				
DiRenzo		Pea	601	D	2.6	6.2	81.5	12.3	.7	-	-	-	-	12,770	13,110	1	2,680	1	-	-
Do.		Rice	3,162	D	5.3	6.0	80.2	13.8	.7	-	-	-	-	12,180	12,870	12	2,790	6	-	-
Pine Grove: Schaeck		Pea	25	T	5.0	6.6	82.9	10.5	.6	-	-	-	-	12,880	13,560	1	2,910+	1	-	-
Pottsville:																				
Marlin		Stove	50	T	5.0	4.9	86.4	8.7	.6	-	-	-	-	12,930	13,610	1	-	-	-	-
Do.		Chestnut	25	T	5.8	4.8	86.4	8.8	.6	-	-	-	-	12,770	13,560	1	-	-	-	-
Do.		Pea	25	T	5.2	5.1	84.9	10.0	.5	-	-	-	-	12,670	13,370	1	2,910+	1	-	-
Do.		Buckwheat No. 1	30	T	6.0	5.9	81.8	12.3	.6	-	-	-	-	12,090	12,860	1	2,910+	1	-	-
Do.		Rice	20	T	6.9	5.4	84.5	10.1	.6	-	-	-	-	12,400	13,320	1	2,910+	1	-	-
Do.		Barley	20	T	5.5	6.5	80.0	13.5	.5	-	-	-	-	11,880	12,570	1	2,910+	1	-	-
Do.		Buckwheat No. 4	15	T	5.7	6.2	80.0	13.8	.5	-	-	-	-	11,900	12,620	1	2,910+	1	-	-
Shenandoah:																				
Rosa		Stove	50	T	5.1	4.3	87.2	8.5	.5	-	-	-	-	12,850	13,540	1	-	-	-	-
Do.		Chestnut	50	T	5.7	4.2	87.1	8.7	.5	-	-	-	-	12,750	13,520	1	-	-	-	-
Do.		Pea	50	T	5.8	4.4	87.1	8.5	.5	-	-	-	-	12,710	13,490	1	2,910+	1	-	-
Do.		Buckwheat No. 1	60	T	6.2	4.5	86.8	8.7	.5	-	-	-	-	12,630	13,460	1	2,910+	1	-	-
Do.		Rice	60	T	5.9	4.3	86.7	9.0	.5	-	-	-	-	12,670	13,460	1	2,910+	1	-	-
Do.		Barley	50	T	7.2	4.9	83.4	11.7	.4	-	-	-	-	12,030	12,960	1	2,910+	1	-	-
Do.		Buckwheat No. 4	50	T	9.4	5.3	81.2	13.5	.3	-	-	-	-	11,470	12,660	1	2,910+	1	-	-
Do.		Buckwheat No. 5	50	T	5.4	5.8	81.6	12.6	.5	-	-	-	-	11,990	12,670	1	2,910+	1	-	-
Spring Glen: Pine Creek		Buckwheat No. 1	8,408	D	3.0	7.6	81.2	11.2	.6	-	-	-	-	13,080	13,480	21	2,670	10	-	-
Tamaqua:																				
Greenwood		..do.	488	D	5.0	4.3	87.3	8.4	.5	-	-	-	-	12,830	13,510	1	-	-	-	-
Do.		Rice	692	D	7.5	4.5	87.2	8.3	.5	-	-	-	-	12,510	13,520	22	2,900	17	-	-
Do.		Barley	11,233	D	7.6	4.6	85.4	10.0	.5	-	-	-	-	12,200	13,210	25	2,910+	15	-	-
Tremont: Pemag		Rice	7,253	D	3.3	7.1	81.4	11.5	.4	-	-	-	-	12,980	13,430	23	2,560	6	-	-
Valley View:																				
Kocher		Stove	780	D	3.1	7.8	83.1	9.1	.6	-	-	-	-	13,320	13,750	1	-	-	-	-
Do.		Chestnut	1,957	D	4.0	7.0	83.2	9.8	.6	-	-	-	-	13,070	13,620	7	2,500	1	-	-
Do.		Pea	2,405	D	3.7	7.4	82.9	9.7	.7	-	-	-	-	13,150	13,670	7	2,580	4	-	-
Do.		Buckwheat No. 1	44,016	D	4.8	7.1	82.6	10.3	.6	-	-	-	-	12,890	13,530	78	2,670	19	-	-
Do.		Rice	3,605	D	5.0	7.1	82.9	10.0	.7	-	-	-	-	12,930	13,610	4	2,670	1	-	-

1/ See Explanation of Symbols, p. 51.

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966–Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[1]	Proximate, percent: Moisture, as-received coal	Proximate, percent: Dry coal: Volatile matter	Proximate, percent: Dry coal: Fixed carbon	Ultimate, percent: Dry coal: Ash	Ultimate, percent: Dry coal: Sulfur	Ultimate, percent: Dry coal: Hydrogen	Ultimate, percent: Dry coal: Carbon	Ultimate, percent: Dry coal: Nitrogen	Ultimate, percent: Dry coal: Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses[1]	Ash-softening temperature, ° F	Number of ash-softening temperatures[1]	Free-swelling index[1]	Hardgrove grindability index[1]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
			PENNSYLVANIA–Continued (Anthracite)–Continued																	
Schuylkill County--Continued																				
Valley View (Continued):																				
Kocher (Continued)		Barley	17,286	D	4.6	7.3	81.1	11.6	.7	-	-	-	-	12,710	13,320	24	2,770	18	-	-
Zerbe: Swatara		Buckwheat No. 1 (OT)	1,002	D	8.1	6.8	80.3	12.9	.7	-	-	-	-	11,960	13,010	4	2,830	2	-	-
			PENNSYLVANIA (Bituminous)																	
Allegheny County																				
Imperial:																				
Champion No. 1	Pittsburgh	1-1/4- by 3/16-inch (W and OT)	480	D	1.6	39.9	51.9	8.2	2.5	-	-	-	-	13,560	13,780	1	2,130	1	8(1)	-
Champion No. 1 (dock coal)	.do	1- by 1/4-inch (W)	3,465	D	4.4	37.6	55.8	6.6	1.5	-	-	-	-	13,410	14,030	22	2,370	6	7½(2) 8(1) 8½(2) 9(1)	-
Wildwood:																				
Wildwood	Thick Freeport	2- by 3/8-inch (W and OT)	183	D	4.6	37.2	54.6	8.2	1.5	-	-	-	-	13,260	13,900	1	-	-	-	-
Do	.do	1-1/4- by 3/8-inch (W)	15,930	D	2.9	37.3	55.4	7.3	1.7	-	-	-	-	13,610	14,020	36	2,380	10	7½(5) 8(3) 8½(2)	-
Armstrong County																				
Avonmore (Westmoreland County):																				
David	.do	..do	11,996	D	2.4	35.1	57.6	7.3	1.5	-	-	-	-	13,830	14,170	19	2,690	8	8(2) 8½(4) 9(2)	-
Do	.do	1-1/4- by 1/4-inch (W)	7,219	D	1.6	35.4	57.0	7.6	1.5	-	-	-	-	13,910	14,130	10	2,700	6	7½(1) 8(2) 8½(3)	-
Do	.do	1-1/4-inch by 0	17,481	D	2.8	34.7	56.3	9.0	1.6	-	-	-	-	13,520	13,910	19	2,750	4	8(3) 8½(1)	-
Cadogan: Cadogan	Lower Kittanning (B)	1-1/2-inch by 0 (W)	13,819	D	2.8	37.8	53.9	8.3	1.9	-	-	-	-	13,540	13,930	22	2,480	6	7(1) 7½(1) 8(2) 8½(2)	-
Edmon:																				
Sarah Bell	Upper Freeport (E)	Run-of-mine, crushed	6,896	D	3.1	33.4	55.1	11.5	2.4	-	-	-	-	13,080	13,500	10	2,300	4	7½(1) 8(1) 8½(2)	-
Do	.do	1-1/2-inch by 0	3,280	D	2.2	33.2	55.9	10.9	2.1	-	-	-	-	13,290	13,590	6	2,280	3	7½(1) 8(1) 9(1)	-
Kittanning:																				
Decker	.do	1-1/4- by 1/4-inch (W)	726	D	2.7	34.5	57.8	7.7	1.0	-	-	-	-	13,610	13,990	4	2,720	2	8(1) 8½(1)	-
Mosgrove No. 3	.do	Run-of-mine	200	T	4.0	30.5	48.5	21.0	1.5	4.4	66.3	1.2	5.6	11,300	11,770	1	2,730	1	7(1)	55
Saline (Westmoreland County):																				
Foster	Lower Kittanning (B)	Run-of-mine, crushed (W and AC)	100,695	D	2.5	36.0	54.6	9.4	2.4	-	-	-	-	13,560	13,920	145	2,560	29	7(2) 7½(7) 8(14) 8½(4) 9(1)	-
Do	.do	1-1/4- by 3/8-inch (W and OT)	8,153	D	2.0	37.3	55.4	7.3	2.1	-	-	-	-	13,990	14,270	13	2,630	4	7(2) 7½(1) 8(1)	-

Yatesboro: Margaret	Upper Freeport (E)	Run-of-mine, crushed to 1-1/4-inch (W and AC).	460	T	3.1	35.0	57.2	7.8	1.6	-	-	-	-	13,600	14,040	1	2,550	1	9(1)	62
Do	.do	..do	62,592	D	3.1	34.4	57.0	8.6	1.5	-	-	-	-	13,540	13,970	67	2,500	14	7½(1) [illegible] 8½(4) 9(5)	-
Butler County																				
Portersville: Western Hickory Tipple	Middle Kittanning (C).	Run-of-mine	48	T	6.8	37.5	47.8	14.7	6.2	-	-	-	-	11,730	12,590	1	2,130	1	6½(1)	52
Do	Lower Freeport (D)	..do	48	T	4.9	34.5	53.6	11.9	1.9	-	-	-	-	12,540	13,190	1	2,260	1	7(1)	53
Cambria County																				
Bakerton: Lancashire No. 15	Lower Kittanning (B)	1-1/2-inch by 0 (W and AC)	780	D	3.7	21.6	71.7	6.7	2.1	-	-	-	-	14,130	14,670	1	-	-	-	-
Do	.do	1-1/4-inch by 0 (W and AC)	47,789	D	3.4	21.8	70.6	7.6	2.2	-	-	-	-	14,000	14,490	61	2,310	16	8(2) 9(4)	-
Barnesboro. C. E. No. 2	Middle Kittanning (C).	Run-of-mine, crushed to 1-inch	150	T	4.8	24.9	62.7	12.4	.8	4.5	77.7	1.2	3.4	12,910	13,560	1	2,910+	1	8½(1)	84
Lula May	.do	Run-of-mine	40	T	4.5	24.0	63.1	12.9	.6	4.5	76.6	1.0	4.4	12,780	13,380	1	2,910+	1	8(1)	81
Carrolltown: Carrolltown No. 1	Upper Freeport (E)	Run-of-mine, crushed to 3/4-inch	275	T	2.6	24.9	62.1	13.0	2.8	4.6	75.9	1.1	2.6	13,140	13,490	1	2,090	1	8½(1)	93
Hastings: Driscoll No. 2 Tipple	.do	1-1/4-inch by 0	22,306	D	3.8	24.9	65.6	9.5	2.3	-	-	-	-	13,490	14,030	25	2,290	6	8½(2) 9(4)	-
Do	Lower Freeport (D)	1-1/4-inch lump (OT)	101	T	2.7	24.5	64.6	10.9	3.4	-	-	-	-	13,430	13,800	1	2,160	1	-	-
Do	.do	1-1/4-inch by 0	491	T	2.7	25.4	66.9	7.7	2.3	-	-	-	-	13,960	14,350	1	2,250	1	9(1)	98
Johnstown: Stineman No. 10	Upper Kittanning (C prime).	5- by 2-inch	876	D	1.9	16.7	72.9	10.4	1.1	-	-	-	-	13,690	13,960	3	-	-	-	-
Do	.do	4- by 1/2-inch	1,885	D	1.2	16.3	74.0	9.7	.9	-	-	-	-	13,860	14,030	3	2,840	1	7½(1)	-
Marsteller: Driscoll No. 5 Tipple	Lower Freeport (D)	Run-of-mine, crushed to 4-inch	790	T	3.1	24.5	65.9	9.6	1.4	-	-	-	-	13,610	14,050	1	2,410	1	9(1)	-
Saint Benedict: Smith	.do	Run-of-mine	6	T	4.3	23.7	67.9	8.4	1.2	4.6	80.9	1.4	3.5	13,590	14,200	1	2,810	1	9(1)	96
Spangler: Springfield No. 4	Lower Kittanning (B)	4- by 1-inch (W)	56	T	3.9	22.9	71.5	5.6	1.3	-	-	-	-	14,210	14,790	1	2,720	1	-	-
Do	.do	[illegible]- by 1/2-inch (W)	60	T	5.4	22.6	71.5	5.9	1.3	-	-	-	-	13,990	14,790	1	2,730	1	-	-
Do	.do	1/2-inch by 0 (W)	264	T	4.0	22.5	65.9	11.6	2.0	-	-	-	-	13,300	13,850	1	2,520	1	9(1)	104
Centre County																				
Clarence: S. and U	.do	Run-of-mine	192	T	2.5	22.4	56.8	20.8	1.1	-	-	-	-	11,880	12,180	1	2,910+	1	9(1)	80
Clarion County																				
Summerville (Jefferson County): Wayland	Lower Freeport (D)	..do	13	T	2.8	35.4	50.5	14.1	2.6	4.5	71.4	1.4	6.0	12,600	13,960	1	2,350	1	7½(1)	53
Clearfield County																				
Bigler: Wilmo No. 1		5- by 2-inch	899	D	1.9	24.0	61.9	14.1	1.7	-	-	-	-	12,950	13,210	3	-	-	-	-
Do		1-1/4- by 3/8-inch (W)	2,349	D	3.4	25.2	67.2	7.6	1.2	-	-	-	-	13,730	14,280	5	2,710	4	8½(1) [illegible]	-
Do		1- by 3/8-inch (W)	780	D	2.6	24.2	66.1	9.7	1.0	-	-	-	-	13,650	14,010	1	2,710	1	9(1)	-
Coalport: Apple No. 4	Lower Freeport (D)	3/4-inch by 0	48	T	2.8	24.2	65.2	10.6	2.3	4.6	78.4	1.4	2.7	13,450	13,840	1	2,370	1	4(1)	96
Apple No. 5	.do	Run-of-mine	24	T	3.0	23.4	64.5	12.1	2.7	4.4	77.2	1.4	2.2	13,200	13,610	1	2,370	1	4(1)	94
Karthaus: Hoffman No. 3	Middle Kittanning (C) and Lower Freeport (D)	1-1/4- by 3/4-inch (W)	600	D	.8	23.4	68.3	7.9	1.8	-	-	-	-	14,190	14,300	1	2,620	1	-	-
Luthersburg: Triangle No. 1 Tipple	Upper Kittanning (C prime).	Run-of-mine, crushed to 2-inch	288	T	4.4	27.9	56.2	15.9	2.7	-	-	-	-	12,300	12,870	1	2,410	1	[illegible]	-
Utahville: Cross Roads No. 3.	Upper Freeport (E)	Run-of-mine, crushed to 3/4-inch (AC).	64	T	4.3	23.4	66.1	10.5	.7	-	-	-	-	13,340	13,940	1	2,910+	1	[illegible]	80

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal[1]	Approximate tons sampled	Kind of sample[2]	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses[2]	Ash-softening temperature, ° F	Number of ash-softening temperatures[2]	Free-swelling index[3]	Hardgrove grindability index[3]
					Moisture, as-received coal	Dry coal														
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as-received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
PENNSYLVANIA—Continued (Bituminous)—Continued																				
Clinton County																				
Pottersdale (Clearfield County):																				
Garden Tipple	Lower Kittanning (B) and Middle Kittanning (C).	Run-of-mine, crushed to 4-inch	432	T	4.1	22.4	66.6	11.0	2.4	-	-	-	-	13,230	13,800	1	2,470	1	9(1)	100
Indiana County																				
Clymer:																				
Imperial Keystone	Lower Kittanning (B)	1-1/4- by 3/4-inch (W)	5,486	D	1.7	28.2	63.0	8.8	2.0	-	-	-	-	13,950	14,190	6	2,630	3	8½(1) 9(2)	-
Do	.do	1-1/4-inch by 0 (W and AC)	34,134	D	2.9	28.7	62.2	9.1	2.2	-	-	-	-	13,720	14,130	36	2,480	7	8(2) 8½(3) 7(3)	-
Peles No. 2	.do	Run-of-mine, crushed to 1-inch	225	T	2.9	27.7	58.9	13.4	4.5	4.6	74.4	1.3	1.8	13,010	13,400	1	2,080	1	8½(1)	-
Dixonville:																				
Mears Tipple	.do	Run-of-mine, crushed to 3/4-inch	549	T	2.8	28.0	60.1	11.9	4.0	-	-	-	-	13,240	13,620	1	2,190	1	8(1)	95
Do	.do	1-inch lump, crushed to 2-inch	119	T	2.8	27.5	56.1	16.4	4.3	-	-	-	-	12,470	12,830	1	2,190	1	-	-
Do	.do	1-inch by 0	311	T	4.5	28.7	59.9	11.4	3.2	-	-	-	-	12,980	13,590	1	2,300	1	8(1)	86
Glen Campbell: Fremar No. 1.	.do	Run-of-mine, crushed to 3/4-inch (AC).	165	T	2.4	28.2	59.9	11.9	.9	4.6	76.5	1.3	4.8	13,210	13,530	1	2,910+	1	5½(1)	77
Heshbon:																				
Virginia No. 20	.do	3- by 5/16-inch (W), crushed to 1-3/4-inch (Run-of-mine, crushed to 3-inch).	231	T	3.6	25.0	66.4	8.6	2.7	-	-	-	-	13,730	14,240	1	2,280	1	-	103
Do	.do	1-1/4- by 1/4-inch (W)	1,254	D	1.9	24.4	67.4	8.2	2.5	-	-	-	-	14,060	14,330	6	2,260	2	9(2)	-
Do	.do	1-1/4-inch by 0	822	D	.7	24.0	67.5	8.5	2.6	-	-	-	-	14,160	14,270	2	2,250	2	9(1)	-
Do	.do	5/16-inch by 0	429	T	3.3	25.1	65.6	9.3	3.2	-	-	-	-	13,680	14,150	1	2,330	1	9(1)	-
Robinson: Friel No. 6	Upper Freeport (E)	Run-of-mine, crushed (AC)	31,821	D	2.9	24.5	65.4	10.1	2.0	-	-	-	-	13,570	13,980	40	2,410	11	8½(1) 9(10)	-
Starford: Glenside No. 2	Lower Kittanning (B) and Lower Freeport (D)	Run-of-mine, crushed to 1-inch	906	T	3.4	27.7	60.7	11.6	3.1	-	-	-	-	13,240	13,710	1	2,300	1	8(1)	-
Mercer County																				
Sharon:																				
Perry-Ross Tipple	Brookville (A)	Run-of-mine	374	T	5.9	38.5	52.6	8.9	1.7	-	-	-	-	12,620	13,410	1	2,130	1	5(1)	55
Do	Middle Kittanning (C).	..do	340	T	4.7	37.2	53.2	9.6	1.6	-	-	-	-	12,730	13,360	1	2,630	1	5(1)	52
Somerset County																				
Acosta:																				
Coal Junction prep. plant	Lower Kittanning (B) and Middle Kittanning (C).	Run-of-mine, crushed to 3/4-inch (50% AC).	415	T	6.3	17.3	69.3	13.4	1.9	-	-	-	-	12,440	13,280	1	2,570	1	5(1)	-
Central City:																				
Reitz No. 3-B	Lower Kittanning (B)	Run-of-mine	108	T	2.6	17.3	70.8	11.9	1.3	4.3	78.8	1.4	2.3	13,300	13,650	1	2,910+	1	9(1)	100
Reitz No. 4	Lower Kittanning (B) and Upper Kittanning (C prime).	8- by 1/2-inch	1,325	D	1.9	16.8	72.3	10.9	1.5	-	-	-	-	13,580	13,830	3	2,710	2	6(1) 6½(1)	-
Venango County																				
Grove City (Mercer County):																				
Baymilton	Brookville (A)	Run-of-mine	384	T	4.7	38.1	45.5	16.4	7.1	-	-	-	-	11,750	12,330	1	2,090	1	4½(1)	-

Westmoreland County																				
Freeport (Armstrong County):																				
Vesturial	Upper Freeport (E)	2- by 3/8-inch (OT)	6,943	D	2.7	36.1	52.6	11.3	2.0	-	-	-	-	13,050	13,410	22	2,360	6	7½(2) 8(2) 8½(3)	-
Do	.do	1- by 1/4-inch	4,620	D	1.5	36.6	54.5	8.9	2.3	-	-	-	-	13,640	13,850	24	2,250	6	7½(2) 8(2) 8½(1) 9(1)	-
Saltsburg (Indiana County):																				
Loyal	.do	Run-of-mine, crushed to 2-inch (W and AC).	330	T	4.1	32.2	57.8	10.0	2.2	4.9	77.1	1.3	4.5	13,260	13,830	1	2,240	1	8(1)	-
Do	.do	1-1/4- by 3/8-inch (W)	487	D	1.2	33.4	59.4	7.2	1.4	-	-	-	-	14,090	14,270	2	-	-	-	-
Do	.do	1-1/2-inch by 0 (W and AC)	181	D	1.5	33.0	60.1	6.9	2.2	-	-	-	-	14,120	14,340	1	-	-	-	-
TENNESSEE																				
Campbell County																				
Habersham:																				
Westbourne	Log Mountain	5- by 3-inch	6,278	D	3.1	41.1	56.5	2.4	.8	-	-	-	-	14,120	14,570	9	-	-	-	-
Do	.do	1-1/2-inch by 0	2,772	D	5.7	36.2	54.5	9.3	1.1	-	-	-	-	12,540	13,300	15	2,460	5	1½(1) 3(1) 3½(2) 5(1)	-
Do	.do	1-1/4-inch by 0	8,967	D	5.5	38.2	55.7	6.1	1.0	-	-	-	-	13,090	13,850	20	2,480	7	1½(1) 3(2) 3½(2) 4(2)	-
Grundy County																				
Coalmont: Ramsey	Sewanee	Run-of-mine, crushed	30,294	D	3.1	29.7	59.3	11.0	.8	-	-	-	-	12,990	13,410	31	2,650	7	6(4) 7(3)	-
UTAH																				
Carbon County																				
Castle Gate: Kenilworth		1-1/4-inch by 0	5,647	D	4.4	43.8	48.0	8.2	.4	-	-	-	-	12,720	13,300	72	-	-	-	-
Helper:																				
Carbon Fuel	Castle Gate B	1-5/8-inch by 0	41,633	D	4.5	45.8	47.3	6.9	.3	-	-	-	-	12,870	13,480	60	2,250	14	2½(1) 3(1)	-
Do	.do	1-1/4-inch by 0	4,714	D	4.7	45.7	47.4	6.9	.3	-	-	-	-	12,810	13,450	70	2,270	2	-	-
Do	.do	3/4-inch by 0	763	D	4.7	45.6	47.3	7.1	.3	-	-	-	-	12,780	13,410	11	-	-	-	-
Hiawatha:																				
King		1-5/8- by 3/16-inch	954	D	4.8	47.0	46.9	6.1	.5	-	-	-	-	12,990	13,650	1	2,060	1	-	-
Do		1- by 3/16-inch	10,529	D	6.4	45.9	48.4	5.7	.5	-	-	-	-	12,820	13,700	14	2,140	5	-	-
Do		3/4-inch by 0	342	D	5.9	46.1	47.7	6.2	.5	-	-	-	-	12,850	13,660	5	-	-	-	-
Rains:																				
Western		6- by 3-inch	633	D	3.5	46.9	46.9	6.2	.8	-	-	-	-	13,240	13,720	4	-	-	-	-
Do		8- by 1-5/8-inch	14,419	D	4.0	45.0	47.2	6.8	.7	-	-	-	-	13,000	13,550	17	2,190	2	-	-
Do		1- by 3/16-inch (OT)	5,982	D	4.2	44.6	46.9	8.5	.7	-	-	-	-	12,720	13,280	11	2,200	4	-	-
Do		1-5/8-inch by 0	18,505	D	4.9	45.0	46.8	8.2	.8	-	-	-	-	12,630	13,280	33	2,180	8	-	-
Wellington:																				
Knight Ideal No. 2		1-1/4- by 1/4-inch	456	D	3.4	40.7	54.1	5.2	.5	-	-	-	-	13,390	13,860	1	-	-	-	-
Do		1- by 1/4-inch	6,234	D	3.5	40.9	54.0	5.1	.4	-	-	-	-	13,350	13,840	11	2,220	4	-	-
Do		1-5/8- by 3/16-inch	2,447	D	5.1	40.7	54.1	5.2	.4	-	-	-	-	13,100	13,800	16	2,200	15	1½(1)	-
Do		1- by 3/16-inch	154	D	4.0	40.8	54.4	4.8	.4	-	-	-	-	13,280	13,830	1	-	-	-	-
Do		3/4-inch by 0	390	D	5.7	40.5	54.1	5.4	.4	-	-	-	-	12,900	13,690	5	-	-	-	-
Emery County																				
Dragerton (Carbon County):																				
Book Cliffs	Lower Sunnyside	Run-of-mine, crushed to 1-5/8-inch	120	T	6.4	40.4	51.5	8.1	1.0	-	-	-	-	12,380	13,230	1	2,350	1	3(1)	48
Do	.do	1- by 1/4-inch (OT)	30	T	6.3	40.8	51.0	8.2	.8	-	-	-	-	12,400	13,230	1	2,450	1	-	-
Do	.do	1-5/8- by 3/16-inch	7,575	D	5.5	40.6	51.9	7.5	.7	-	-	-	-	12,580	13,320	30	2,430	10	3(1)	-

[1] See Explanation of Symbols (p. 3).

[2] Numbers above 1 indicate the number of deliveries averaged.

[3] Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal 1/	Approximate tons sampled	Kind of sample 2/	Proximate, percent: Moisture, as-received coal	Proximate, percent (Dry coal): Volatile matter	Proximate, percent (Dry coal): Fixed carbon	Ultimate, percent (Dry coal): Ash	Ultimate, percent (Dry coal): Sulfur	Ultimate, percent (Dry coal): Hydrogen	Ultimate, percent (Dry coal): Carbon	Ultimate, percent (Dry coal): Nitrogen	Ultimate, percent (Dry coal): Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses 3/	Ash-softening temperature, ° F	Number of ash-softening temperatures 3/	Free-swelling index 3/	Hardgrove grindability index 3/
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
UTAH–Continued																				
Emery County --Continued																				
Dragerton (Carbon County) (Continued):																				
Book Cliffs (Continued)....	Lower Sunnyside.......	1-5/8-inch by 0..................	4,902	D	5.9	40.5	52.0	7.5	.7	-	-	-	-	12,560	13,340	15	2,450	5	-	-
VIRGINIA																				
Buchanan County																				
Conaway:																				
Little Bear Tipple No. 2...	Eagle and Hagy........	Run-of-mine, crushed to 1-1/4-inch (W and OT).	560	T	3.0	30.7	60.7	8.6	1.8	-	-	-	-	13,660	14,080	1	2,520	1	5½(1)	-
Margaret Ann Tipple........	....	6- by 1-1/4-inch (W).............	50	T	3.1	32.1	61.2	6.7	1.3	-	-	-	-	13,980	14,430	1	2,730	1	-	-
Do......................	....	1-1/4- by 1/4-inch (W)............	165	T	5.3	32.7	60.9	6.4	1.3	-	-	-	-	13,680	14,450	1	2,730	1	-	-
Do......................	....	1/4-inch by 0....................	480	T	4.0	31.5	59.2	9.3	1.8	-	-	-	-	13,400	13,960	1	2,500	1	7(1)	68
Star Tipple..............	....	Run-of-mine, crushed to 1-1/4-inch	460	T	3.1	30.9	60.8	8.3	1.4	-	-	-	-	13,700	14,140	1	2,420	1	7½(1)	-
Thomas Tipple..............	Hagy..................	Run-of-mine, crushed to 2-inch....	75	T	3.2	30.9	62.9	6.2	.8	-	-	-	-	14,070	14,540	1	2,910+	1	5½(1)	66
Grundy:																				
Bonnie Bess Tipple.........	....	Run-of-mine, crushed to 1-1/2-inch	410	T	4.3	30.1	60.4	9.5	.7	-	-	-	-	13,310	13,910	1	2,910+	1	8(1)	62
Edith Fay Tipple...........	Splash Dam and Kennedy	Modified Run-of-mine, crushed to 1-1/4-inch (80% of 1-1/4- by 1/4-inch removed) (W).	520	T	5.1	27.8	64.5	7.7	.8	-	-	-	-	13,560	14,290	1	2,620	1	-	80
Do......................	.do...................	1-1/4- by 1/4-inch (W)............	125	T	3.8	28.4	66.4	5.2	.7	-	-	-	-	14,110	14,670	1	2,760	1	8(1)	-
Leetown Tipple.............	....	3- by 3/8-inch (W) (Run-of-mine, crushed to 3-inch).	150	T	4.8	31.0	61.5	7.5	.9	-	-	-	-	13,720	14,410	1	2,860	1	-	-
Do......................	....	3/8-inch by 0 (AC)................	250	T	3.6	30.2	60.8	9.0	1.0	-	-	-	-	13,620	14,130	1	2,680	1	8(1)	74
Levisa Tipple..............	....	Run-of-mine, crushed to 1-1/2-inch (W).	310	T	4.3	29.7	62.5	7.9	1.0	-	-	-	-	13,590	14,200	1	2,630	1	7½(1)	71
Little Bear Tipple No. 1...	....	Run-of-mine, crushed to 1-1/4-inch	520	T	3.0	31.3	59.9	8.8	1.7	-	-	-	-	13,600	14,020	1	2,410	1	8(1)	53
Lynn Camp Tipple...........	....	2-inch lump, crushed to 2-inch....	70	T	1.9	30.2	62.6	7.2	.8	-	-	-	-	14,120	14,390	1	2,780	1	-	-
Do......................	....	2- by 1-inch......................	70	T	1.9	30.3	61.7	8.0	.9	-	-	-	-	13,990	14,260	1	2,730	1	-	-
Do......................	....	1-inch by 0.......................	430	T	2.4	31.4	62.8	5.8	.8	-	-	-	-	14,300	14,650	1	2,780	1	6½(1)	70
Melrose Tipple.............	Kennedy...............	Run-of-mine, crushed to 1-1/2-inch	220	T	2.1	25.6	69.1	5.3	1.2	-	-	-	-	14,450	14,760	1	2,290	1	9(1)	-
Riverside Tipple...........	.do...................	Run-of-mine, crushed to 1-1/4-inch	230	T	2.9	26.7	67.5	5.8	1.4	-	-	-	-	14,280	14,710	1	2,190	1	9(1)	-
Rockhouse prep. plant......	Splash Dam............	5- by 3/16-inch (W) (Run-of-mine, crushed to 5-inch).	200	T	6.6	30.6	64.5	4.9	1.0	-	-	-	-	13,670	14,640	1	2,680	1	-	-
Do......................	.do...................	3/16-inch by 0....................	200	T	5.0	29.0	62.8	8.2	1.2	-	-	-	-	13,520	14,230	1	2,650	1	8½(1)	81
Wolfpen No. 1 Tipple.......	Eagle.................	1-1/2- by 1/4-inch (W) (Run-of-mine, crushed to 1-1/2-inch).	180	T	3.7	33.3	62.9	3.8	.7	-	-	-	-	14,290	14,840	1	2,910+	1	-	-
Do......................	.do...................	1/4-inch by 0.....................	120	T	3.2	29.7	58.8	11.5	.9	-	-	-	-	13,150	13,580	1	2,520	1	8(1)	64
Wolfpen No. 2 Tipple.......	Splash Dam............	Run-of-mine, crushed to 1-1/2-inch	150	T	2.8	30.1	58.7	11.2	1.1	-	-	-	-	13,290	13,670	1	2,730	1	7½(1)	60
Harman:																				
Clintwood Tipple...........	Clintwood.............	Run-of-mine, crushed to 1-inch....	925	T	2.4	32.6	60.2	7.2	.9	-	-	-	-	13,960	14,300	1	2,790	1	7(1)	60
Harman.....................	Splash Dam............	6- by 3-inch (W)..................	20	T	2.6	29.7	65.6	4.7	.7	-	-	-	-	14,460	14,850	1	2,670	1	-	-
Do......................	.do...................	3- by 2-inch (W)..................	25	T	2.1	29.5	65.6	4.9	.6	-	-	-	-	14,540	14,850	1	2,910+	1	-	-
Do......................	.do...................	2- by 1-1/4-inch (W)..............	70	T	2.6	29.4	65.4	5.2	.6	-	-	-	-	14,400	14,780	1	2,910+	1	-	-
Do......................	.do...................	1-1/4-inch by 0 (W)...............	615	T	5.3	30.0	64.5	5.5	.7	-	-	-	-	13,780	14,710	1	2,840	1	8(1)	74
Harman Spur Tipple.........	Clintwood.............	Run-of-mine, crushed to 1-1/4-inch	250	T	3.0	30.4	62.6	7.0	.6	-	-	-	-	12,290	13,360	1	2,850	1	1½(1)	70
Hurley:																				
Kelsa Tipple...............	Splash Dam, Hagy and Blair.	Run-of-mine, crushed to 1-1/4-inch (1-1/4- by 3/8-inch (W)).	610	T	4.5	31.6	61.3	7.1	.9	-	-	-	-	13,680	14,320	1	2,730	1	9(1)	66
Race Fork Tipple...........	Blair.................	Run-of-mine, crushed to 1-1/2-inch	255	T	3.4	30.8	59.6	9.6	.9	-	-	-	-	13,390	13,860	1	2,620	1	8½(1)	64
Do......................	Splash Dam............	..do..............................	490	T	2.6	31.3	56.7	12.0	1.2	-	-	-	-	13,170	13,520	1	2,650	1	7½(1)	58
Keen Mountain:																				
Keen Mountain..............	Lower Banner..........	3/4- by 1/4-inch (W)..............	2,830	D	2.2	22.5	69.2	8.3	1.2	-	-	-	-	14,030	14,350	4	2,750	2	7½(1)	-

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Do	do	1-1/4-inch by 0	41,795	D	4.2	22.4	68.6	9.0	1.2	-	-	-	-	13,560	14,160	48	2,650	8	7½(2) 8(2) 8½(3) 9(1)	91
Oakwood:																				
Oakwood No. 1 Tipple	Kennedy and Raven	8-inch lump	10	T	1.9	23.3	72.7	4.0	.6	-	-	-	-	14,760	15,050	1	2,590	1	-	-
Do	.do	8- by 4-inch (OT)	25	T	1.9	22.9	73.7	3.4	.6	-	-	-	-	14,940	15,230	1	2,470	1	-	-
Do	.do	4- by 1-3/4-inch (W and OT)	35	T	2.8	23.4	73.3	3.3	.6	-	-	-	-	14,830	15,260	1	2,340	1	-	-
Do	.do	1-3/4- by 1-inch (W and OT)	50	T	3.0	23.3	73.1	3.6	.7	-	-	-	-	14,750	15,210	1	2,460	1	-	-
Do	.do	1-inch by 0 (W)	295	T	8.7	23.8	68.9	7.3	1.0	-	-	-	-	13,250	14,510	1	2,600	1	8½(1)	92
Vansant:																				
Coronet Jewell No. 2 prep. plant.	Jewell	4-inch lump (W and OT)	110	T	2.2	24.0	73.3	2.7	.7	-	-	-	-	14,910	15,250	1	2,160	1	-	-
Do	.do	4- by 2-inch (W and OT)	140	T	2.3	23.2	74.3	2.5	.8	-	-	-	-	14,910	15,260	1	2,160	1	-	-
Do	.do	2- by 1-inch (W and OT)	190	T	3.0	23.0	74.0	3.0	.8	-	-	-	-	14,790	15,250	1	2,150	1	-	-
Do	.do	1- by 3/8-inch (W)	270	T	3.7	23.5	73.2	3.3	.8	-	-	-	-	14,620	15,180	1	2,230	1	-	-
Do	.do	3/8-inch by 0 (W and AC)	890	T	8.5	24.4	70.9	4.7	.9	-	-	-	-	13,620	14,880	1	2,360	1	9(1)	98
Dickenson County																				
Coeburn (Wise County):																				
Moss No. 1	Clintwood	3- by 2-inch (W)	1,404	D	2.9	33.3	62.6	4.1	.6	-	-	-	-	14,410	14,850	2	-	-	-	-
Haysi: Dudley Tipple	Hagy	Run-of-mine, crushed to 1-1/4-inch	120	T	1.4	28.8	61.1	10.1	2.5	-	-	-	-	13,760	13,960	1	2,230	1	6(1)	78
Nora:																				
Cassell Tipple	Upper Banner	Run-of-mine, crushed to 2-inch	150	T	2.2	31.7	55.2	13.1	.6	-	-	-	-	13,130	13,430	1	2,620	1	6(1)	58
Honey Branch Tipple	Upper and Lower Banner	..do	325	T	2.0	31.5	59.7	8.8	.9	-	-	-	-	13,910	14,190	1	2,370	1	7½(1)	63
Lambert Tipple	Lower Banner	Run-of-mine, crushed to 1-1/2-inch	450	T	2.3	31.0	58.5	10.5	.9	-	-	-	-	13,510	13,830	1	2,320	1	7(1)	63
Lee County																				
Pennington Gap:																				
Southwest Tipple		Run-of-mine, crushed to 1-1/4-inch	220	T	3.7	37.7	51.5	10.8	2.4	-	-	-	-	12,760	13,250	1	2,250	1	4½(1)	45
Saint Charles:																				
Benedict No. 5	Taggart	Modified Run-of-mine, crushed to 1-inch (6- by 4-inch and 1/4-inch by 0 removed) (OT).	80	T	2.5	40.4	55.4	4.2	.6	-	-	-	-	14,170	14,530	1	2,300	1	-	-
Do	.do	6- by 4-inch	10	T	2.6	40.2	57.0	2.8	.7	5.5	82.5	1.5	7.0	14,420	14,800	1	2,290	1	-	-
Do	.do	1/4-inch by 0	60	T	3.1	36.4	57.0	6.6	.7	-	-	-	-	13,630	14,070	1	2,250	1	6(1)	54
Russell County																				
Dante:																				
Moss No. 2	Tiller	1-1/4- by 1/4-inch (W)	1,377	D	1.8	31.1	63.4	5.5	.5	-	-	-	-	14,410	14,680	5	2,400	4	7(1) 7½(3)	-
Moss No. 2-A	.do	1-1/4-inch by 0 (W)	49,009	D	2.3	29.6	59.4	11.0	.4	-	-	-	-	13,360	13,670	69	2,250	22	4(2) 5(3) 5½(9) 6(6) 6½(1) 7(1)	-
Moss No. 3	Thick Tiller	1-1/4- by 1/4-inch (W and OT)	436	D	2.4	30.4	64.4	5.2	.5	-	-	-	-	14,490	14,850	1	2,460	1	7(1)	-
Do	.do	1- by 1/4-inch (W)	10,354	D	2.8	30.2	64.6	5.2	.5	-	-	-	-	14,360	14,770	35	2,420	11	7(2) 7½(8) 8(1)	-
Do	.do	3/4- by 1/4-inch (W)	509	D	1.3	30.2	63.9	5.9	.5	-	-	-	-	14,470	14,660	2	2,430	2	7½(2)	-
Do	.do	2-inch by 0 (W)	42,396	D	2.4	29.8	64.6	5.6	.5	-	-	-	-	14,340	14,690	49	2,430	9	7(1) 7½(6) 8(2)	-
Do	.do	1-1/4-inch by 0 (W)	28,327	D	2.3	29.9	64.9	5.2	.5	-	-	-	-	14,440	14,780	35	2,450	7	7(2) 7½(3) 8(2)	71
Do	.do	3/4-inch by 0 (W)	16,527	D	2.0	29.5	63.8	6.7	.5	-	-	-	-	14,190	14,470	17	2,460	5	6½(1) 7(3) 7½(1)	-
Moss No. 3-A	.do	Run-of-mine, crushed (W)	388,647	D	2.4	29.4	63.8	6.8	.5	-	-	-	-	14,140	14,480	526	2,430	76	6(3) 6½(28) 7([illegible]) 7½([illegible]) 8(2)	-
Do	.do	1-1/4- by 1/4-inch (W)	929	D	2.0	30.1	64.8	5.1	.5	-	-	-	-	14,490	14,780	3	2,420	1	7½(1)	-
Do	.do	1-1/4- by 1/8-inch (W)	8,010	D	2.1	29.0	63.8	7.2	.5	-	-	-	-	14,110	14,420	20	2,430	6	6½(1) 7(4) 7½(1)	-

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1946—Continued

State, county, town, and mine	Bed	Size of coal 3/	Approximate tons sampled	Kind of sample 1/	Proximate, percent: Moisture as-received coal	Proximate, percent: Dry coal: Volatile matter	Proximate, percent: Dry coal: Fixed carbon	Proximate, percent: Dry coal: Ash	Ultimate, percent: Dry coal: Sulfur	Ultimate, percent: Dry coal: Hydrogen	Ultimate, percent: Dry coal: Carbon	Ultimate, percent: Dry coal: Nitrogen	Ultimate, percent: Dry coal: Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses 2/	Ash-softening temperature, ° F	Number of ash-softening temperatures 2/	Free-swelling index 1/	Hardgrove grindability index 1/
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
VIRGINIA—Continued																				
Tazewell County																				
Bishop: Bishop (dock coal)...	Pocahontas No. 3......	3/4-inch by 0 (W)................	9,071	D	3.5	21.0	74.7	4.3	.6	-	-	-	-	14,460	14,990	24	2,310	6	7½(1) 8(3) 8½(1) 9(1)	-
Raven:																				
New Garden prep. plant......	Raven................	4-inch lump................	70	T	2.1	28.0	68.4	3.6	1.0	-	-	-	-	14,630	14,990	1	2,080	1	-	-
Do..................	.do..................	4- by 2-inch (W and OT)..........	70	T	2.5	28.9	67.7	3.4	.8	-	-	-	-	14,710	15,090	1	2,080	1	-	-
Do..................	.do..................	2- by 1-inch (W)..................	90	T	3.8	27.8	68.3	3.9	.8	-	-	-	-	14,440	15,010	1	2,160	1	-	-
Do..................	.do..................	1- by 3/8-inch (W)..................	90	T	4.1	28.1	67.9	4.0	.7	-	-	-	-	14,390	15,000	1	2,210	1	-	-
Do..................	.do..................	3/8-inch by 0..................	500	T	3.9	27.9	65.1	7.0	.7	-	-	-	-	13,960	14,530	1	2,350	1	8(1)	82
Richlands: Norma Jay Tipple..	Jawbone..............	Run-of-mine, crushed to 2-inch....	235	T	2.1	26.0	57.2	16.8	.6	-	-	-	-	12,610	12,880	1	2,780	1	4½(1)	68
Wise County																				
Appalachia:																				
Cane Patch (Crossbrook No. 3).	Imboden and Kelly.....	Run-of-mine, crushed.............	35,812	D	4.5	33.7	57.3	9.0	.7	-	-	-	-	13,070	13,690	44	2,770	12	4(1) 5(1) 6½(1) 7(5) 7½(3) 8(1)	-
Crossbrook No. 1...........	Imboden..............	..do.........................	67,625	D	4.0	33.8	55.9	10.3	.7	-	-	-	-	12,980	13,510	90	2,770	23	6(3) 7(8) 7½(11) 8(1)	-
Norton:																				
Dixiana..................	Taggart..............	Run-of-mine, crushed to 1-1/4-inch (W).	1,010	T	5.9	35.8	61.7	2.5	.7	5.3	84.3	1.4	5.8	14,150	15,040	1	2,630	1	8(1)	54
Wharton Tipple............	....	Run-of-mine, crushed to 2-inch....	400	T	3.0	32.0	56.5	11.5	1.5	-	-	-	-	13,150	13,560	1	2,450	1	9(1)	64
Pardee:																				
Pardee..................	High Splint...........	6-inch lump......................	165	T	2.7	35.1	61.6	3.3	.6	-	-	-	-	14,140	14,530	1	2,540	1	-	-
Do..................	.do..................	6- by 3-inch......................	165	T	2.6	36.0	61.1	2.9	.6	-	-	-	-	14,210	14,590	1	2,540	1	-	-
Do..................	.do..................	3- by 2-inch......................	55	T	2.6	36.9	60.4	2.7	.6	5.2	82.9	1.7	6.9	14,300	14,680	1	2,910+	1	-	-
Do..................	.do..................	1-1/4- by 1/4-inch (2- by 1-1/4-inch, crushed to 1-1/4-inch).	150	T	2.9	36.4	59.7	3.9	.7	-	-	-	-	14,040	14,460	1	2,910+	1	-	-
Do..................	.do..................	1/4-inch by 0......................	80	T	4.7	35.3	59.2	5.5	.8	-	-	-	-	13,480	14,140	1	2,620	1	6(1)	50
Roda: Roda Tipple.	Morris...............	Run-of-mine, crushed.............	6,981	D	3.7	35.3	55.9	8.8	.8	-	-	-	-	13,120	13,620	12	2,900	5	4(1) 5(1) 5½(3)	-
Wise: Glamorgan No. 1.......	Glamorgan............	Run-of-mine, crushed to 2-inch....	140	T	2.5	31.7	58.6	9.7	1.1	4.9	77.4	1.6	5.3	13,530	13,880	1	2,340	1	9(1)	64
WEST VIRGINIA																				
Barbour County																				
Philippi:																				
Badger No. 10..............	Middle Kittanning.....	1-1/4- by 1/4-inch (W)............	9,247	D	2.8	33.4	58.1	8.5	1.2	-	-	-	-	13,740	14,130	19	2,820	7	6½(1) 7(1) 7½(3) 8(2)	-
Do..................	.do..................	3/4- by 3/8-inch (W)..............	2,100	D	1.2	33.9	57.9	8.2	1.1	-	-	-	-	14,000	14,170	3	2,910+	1	6½(1)	-
Do..................	.do..................	3/4- by 1/4-inch (W)..............	2,739	D	3.5	33.7	57.9	8.4	1.1	-	-	-	-	13,660	14,150	25	2,910+	6	6½(1) 7(1) 7½(3) 8(1)	-

Do.	.do.	1-inch by 0 (W).	5,920	D	1.7	33.1	57.5	9.4	1.3	-	-	-	-	13,690	13,930	8	2,760	3	7(1) 7½(1) 8(1)	-
Boone County																				
Clothier (Logan County):																				
Hampton No. 4	Cedar Grove	5- by 2-inch (W)	2,135	D	1.8	37.4	57.7	4.9	.7	-	-	-	-	14,270	14,530	3	-	-	-	-
Do.	.do.	1-1/4- by 1/4-inch (W)	39,762	D	2.8	37.1	57.6	5.3	1.0	-	-	-	-	14,080	[illegible]	79	2,710	25	6½(5) 7(8) 7½(6) 8(7)	-
Do.	.do.	1- by 1/4-inch (W)	833	D	3.2	36.9	58.1	5.0	1.1	-	-	-	-	14,080	14,550	3	2,660	3	8(3)	-
Do.	.do.	1-1/2-inch by 0 (W)	43,008	D	2.3	37.2	57.4	5.4	1.0	-	-	-	-	14,130	[illegible]	46	2,720	8	6(1) 6½(3) 7(1) 7½(3)	-
Do.	.do.	1-1/4-inch by 0 (W)	56,122	D	3.2	36.7	57.6	5.7	1.0	-	-	-	-	13,960	[illegible]	75	2,640	23	4½(1) 5(1) 6(2) 6½(2) 7(8) 7½(6) 8(3)	-
Hampton No. 4 (dock coal)	.do.	1-1/4- by 1/4-inch (W)	9,138	D	3.0	37.0	57.8	5.2	.9	-	-	-	-	14,020	[illegible]	43	2,720	10	5½(1) 7(1) 7½(6) 8(2)	-
Do.	.do.	1- by 1/4-inch (W)	4,147	D	3.8	36.2	58.1	5.7	1.0	-	-	-	-	13,810	14,350	13	2,810	4	7(1) 7½(1) 8(2)	-
Garrison:																				
Dorothy No. 2	No. 2 Gas	Run-of-mine, crushed to 2-inch	80	T	2.6	35.3	55.8	8.9	2.6	5.0	77.4	1.3	4.8	13,600	[illegible]	1	2,280	1	8(1)	56
Ferndale No. 1	.do.	Run-of-mine, crushed to 1-1/2-inch	150	T	2.6	34.6	56.1	9.3	2.7	5.0	77.1	1.2	4.7	13,500	[illegible]	1	2,290	1	8(1)	55
Jeffrey:																				
Spruce River No. 9-A	Chilton	6- by 3-inch (W)	75	T	2.9	39.2	55.9	4.9	.6	-	-	-	-	13,910	[illegible]	1	2,910+	1	-	-
Do.	.do.	3- by 1/4-inch (W)	360	T	4.2	38.9	56.5	4.6	.6	-	-	-	-	13,740	[illegible]	1	2,910+	1	-	44
Do.	.do.	1-1/4- by 1/4-inch (W)	250	T	4.5	38.7	56.5	4.8	.6	-	-	-	-	13,660	[illegible]	1	2,910+	1	-	-
Do.	.do.	1/4-inch by 0	145	T	5.3	33.5	53.0	13.5	.7	4.7	72.8	.7	7.6	12,140	[illegible]	1	2,540	1	6½(1)	-
Twilight: Premium	Winifrede	Run-of-mine, crushed to 1-1/2-inch	340	T	3.6	31.9	58.2	9.9	.7	-	-	-	-	13,170	[illegible]	1	2,910+	1	7(1)	42
Van: Van (dock coal)	Coalburg	1-1/4- by 1/4-inch (W)	2,015	D	2.9	37.3	56.2	6.5	.7	-	-	-	-	13,660	[illegible]	3	2,560	2	6½(1) 7½(1)	-
Fayette County																				
Beards Fork:																				
Beards Fork	Eagle	Run-of-mine, crushed to 1-1/4-inch (W).	800	T	3.1	32.2	61.5	6.3	.9	5.1	82.0	1.7	4.0	14,160	[illegible]	1	2,790	1	8(1)	72
Do.		..do.	39,868	D	3.4	31.6	60.5	7.9	.9	-	-	-	-	13,770	14,250	49	2,730	6	7(1) 7½(4) 8(2)	64
Bellwood: Bellwood	Pocahontas No. 6	Run-of-mine, crushed to 1-1/4-inch	200	T	2.2	20.4	66.1	13.5	1.0	4.1	77.1	1.0	3.3	13,010	13,300	1	2,910+	1	8(1)	87
Cannelton:																				
Lady Dunn No. 2 prep. plant.	Powellton, Winifrede and No. 2 Gas.	Run-of-mine, crushed to 3-inch (W)	1,800	T	4.0	36.6	58.3	5.1	.7	-	-	-	-	13,830	[illegible]	1	2,910+	1	7½(1)	46
Crown Hill (Kanawha County):																				
Riverton No. 23	Powellton	Run-of-mine	100	T	4.0	31.1	64.6	4.3	.6	4.8	81.2	1.5	7.6	13,600	[illegible]	1	2,910+	1	2(1)	61
Hansford: Milburn	No. 2 Gas	Run-of-mine, crushed to 1-1/2-inch (W).	540	T	2.6	32.7	59.3	8.0	1.9	-	-	-	-	13,820	[illegible]	1	2,620	1	7½(1)	66
Kimberly: Kimberly Tipple	Little Eagle	Run-of-mine, crushed to 2-inch	100	T	2.5	33.0	58.4	8.6	.8	-	-	-	-	13,690	[illegible]	1	2,910+	1	8(1)	58
Kingston:																				
Laura Tipple	Big Eagle	Run-of-mine, crushed to 1-1/4-inch	100	T	5.3	31.2	62.2	6.5	.6	-	-	-	-	13,770	[illegible]	1	2,910+	1	7½(1)	73
Do.	Powellton	..do.	150	T	4.2	30.2	61.1	8.7	.8	-	-	-	-	13,610	[illegible]	1	2,700	1	[illegible](1)	71
Montgomery (Kanawha County):																				
Eagle Tipple	No. 5 Block	Run-of-mine, crushed to 2-inch	480	T	3.1	35.4	59.3	5.3	.7	-	-	-	-	13,810	[illegible]	1	2,910+	1	6(1)	44
Page:																				
Hawks Nest Tipple	Big Eagle	..do.	550	T	3.5	29.7	61.4	8.9	.6	-	-	-	-	13,580	[illegible]	1	2,910+	1	8(1)	66
Do.	Little Eagle	..do.	260	T	2.1	32.7	59.6	7.7	.8	-	-	-	-	14,040	[illegible]	1	2,910+	1	6(1)	61
Do.	No. 2 Gas	..do.	250	T	2.7	33.5	60.3	6.2	.9	-	-	-	-	14,040	[illegible]	1	2,740	1	9(1)	59
Robson:																				
Robson Tipple	Peerless	..do.	80	T	2.1	34.7	57.5	7.8	2.2	-	-	-	-	13,910	[illegible]	1	[illegible]	1	6½(1)	59
Do.	No. 2 Gas	..do.	135	T	3.2	30.6	59.1	10.3	.8	-	-	-	-	13,310	[illegible]	1	2,910+	1	9(1)	61

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966 – Continued

State, county, town, and mine	Bed	Size of coal 1/	Approximate tons sampled	Kind of sample 2/	Proximate, percent: Moisture, as-received coal	Proximate, percent: Dry coal: Volatile matter	Proximate, percent: Dry coal: Fixed carbon	Proximate, percent: Dry coal: Ash	Ultimate, percent: Dry coal: Sulfur	Ultimate, percent: Dry coal: Hydrogen	Ultimate, percent: Dry coal: Carbon	Ultimate, percent: Dry coal: Nitrogen	Ultimate, percent: Dry coal: Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses 3/	Ash-softening temperature, ° F	Number of ash-softening temperatures 3/	Free-swelling index 4/	Hardgrove grindability index 5/
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
			WEST VIRGINIA–Continued																	
Fayette County--Continued																				
Spring Dale: Hillview	Fire Creek	Run-of-mine	155	T	2.1	18.4	71.0	10.6	1.3	4.2	80.3	1.1	2.5	13,620	13,910	1	2,780	1	9(1)	96
Harrison County																				
Clarksburg: Dawson	Pittsburgh	1-1/4- by 1/4-inch (W and AC)	457	D	2.0	42.6	50.9	6.5	2.5	-	-	-	-	13,850	14,140	3	2,130	3	7½(1) 8(2)	-
Dola:																				
Compass No. 2	.do	5- by 2-inch (W)	558	D	1.3	42.8	48.8	3.3	3.6	-	-	-	-	13,670	13,850	2	-	-	-	-
Do	.do	1-1/4- by 1/4-inch (W)	4,214	D	1.7	43.2	49.5	7.3	3.4	-	-	-	-	13,750	13,990	7	2,090	4	5½(1) 7(1) 7½(2)	-
Kanawha County																				
Burnwell:																				
Imperial No. 8	No. 2 Gas	Modified Run-of-mine, crushed to 2-inch (30% of 1/4-inch by 0 removed) (W and AC).	430	T	3.3	35.8	56.3	7.9	1.7	5.1	78.6	1.3	5.4	13,620	14,080	1	2,820	1	-	57
Do	.do	1/4-inch by 0 (AC)	80	T	6.4	34.5	55.3	10.2	2.0	-	-	-	-	12,800	13,680	1	2,700	1	8½(1)	-
Cedar Grove:																				
Cedar Grove Loading Dock	Coalburg and No. 5 Block.	Run-of-mine, crushed to 1-1/2-inch	680	T	4.8	34.8	49.1	16.1	.8	-	-	-	-	11,900	12,500	1	2,910+	1	4(1)	-
Crown Hill: Riverton Tipple	Peerless	Run-of-mine, crushed to 2-inch	400	T	1.7	34.2	56.6	9.2	3.2	-	-	-	-	13,640	13,880	1	2,170	1	8(1)	61
Decota:																				
Carbon No. 9		2- by 1/4-inch (W)	2,708	D	1.5	33.5	61.4	5.1	1.0	-	-	-	-	14,410	14,630	6	2,910+	3	7(1) 7½(1) 8(1)	-
Do		1-1/4- by 1/4-inch (W)	23,220	D	2.2	34.2	60.6	5.2	1.0	-	-	-	-	14,310	14,630	42	2,900	14	7(2) 7½(8) 8(3) 8½(1)	-
Do		1- by 1/4-inch (W)	8,048	D	1.4	34.8	59.1	6.1	1.0	-	-	-	-	14,270	14,470	12	2,910+	4	6½(2) 7½(2)	-
Eastbank: Ford	Winifrede	Run-of-mine, crushed to 2-inch	280	T	4.5	35.0	58.3	6.7	.6	-	-	-	-	13,270	13,900	1	2,910+	1	5½(1)	48
Olcott:																				
Olcott Tipple	.do	Modified Run-of-mine, crushed to 2-inch (6- by 3-inch removed).	52	T	4.4	37.7	53.6	8.7	.7	-	-	-	-	13,030	13,630	1	2,910+	1	5(1)	41
Do	.do	6- by 3-inch	20	T	3.7	38.9	55.3	5.8	.6	-	-	-	-	13,600	14,120	1	2,910+	1	-	-
Pond Gap:																				
Bell Creek No. 3	No. 5 Block	5- by 3-inch (W)	4,136	D	2.7	39.6	53.6	6.8	.8	-	-	-	-	13,590	13,960	8	-	-	-	-
Do	.do	6- by 2-inch (W)	240	T	2.9	37.5	55.1	7.4	.7	-	-	-	-	13,510	13,910	1	2,910+	1	-	40
Do	.do	5- by 2-inch (W)	2,598	D	2.6	38.9	53.6	7.5	.8	-	-	-	-	13,480	13,830	6	-	-	-	-
Do	.do	2- by 1-1/4-inch (W)	100	T	2.4	37.5	54.8	7.7	.7	-	-	-	-	13,540	13,870	1	2,910+	1	-	-
Do	.do	1-1/4- by 3/8-inch (W)	90	T	2.9	37.2	55.3	7.5	.8	-	-	-	-	13,480	13,880	1	2,910+	1	6(1)	-
Do	.do	1-1/4- by 1/4-inch (W)	532	D	3.6	39.2	54.3	6.5	.8	-	-	-	-	13,470	13,970	3	2,910+	3	4½(2) 5½(1)	-
Do	.do	2-inch by 0	260	T	6.7	33.0	51.0	16.0	.8	-	-	-	-	11,440	12,260	1	2,910+	1	-	-
Quick:																				
Bell Creek No. 5	.do	6- by 3-inch (W)	420	T	3.1	37.7	53.2	9.1	.9	-	-	-	-	13,140	13,560	1	2,910+	1	-	43
Do	.do	3- by 2-inch (W)	190	T	3.5	38.9	53.1	8.0	.8	-	-	-	-	13,250	13,730	1	2,910+	1	-	-
Do	.do	2- by 1/2-inch (W)	400	T	3.8	38.5	53.4	8.1	.8	-	-	-	-	13,190	13,710	1	2,910+	1	-	-
Do	.do	1-1/4- by 3/8-inch (W)	125	T	4.3	39.3	54.1	6.6	.7	5.2	78.4	1.4	7.7	13,330	13,930	1	2,910+	1	6½(1)	-
Winifrede:																				
Carbon No. 6 prep. plant	No. 5 Block and Winifrede.	6- by 3-inch (W)	130	T	2.5	37.9	57.6	4.5	.7	-	-	-	-	13,990	14,350	1	2,910+	1	-	40
Do	do	3- by 2-inch (W)	100	T	2.7	37.1	57.6	5.3	.8	-	-	-	-	13,820	14,200	1	2,910+	1	-	-

Do	.do	1-1/4- by 1/4-inch (W)	400	T	4.6	36.5	58.3	5.2	.8	-	-	-	-	13,440	14,090	1	2,910+	1	6(1)	-
Do	.do	2-inch by 0 (W)	560	T	4.9	37.0	57.8	5.2	.8	-	-	-	-	13,430	14,120	1	2,910+	1	-	-
Logan County																				
Amherstdale:																				
Guyan No. 1	Cedar Grove	6- by 2-inch (W)	14,999	D	1.7	37.2	56.2	6.6	1.0	-	-	-	-	14,030	14,260	26	-	-	-	-
Do	.do	1-1/4-inch by 0 (W)	1,170	D	3.6	36.6	56.7	6.6	1.2	-	-	-	-	13,770	14,280	2	2,750	2	8(1)	-
Guyan No. 1 (dock coal)	.do	1-1/4- by 1/4-inch (W)	334	D	3.8	36.8	57.8	5.4	.9	-	-	-	-	13,870	14,420	2	2,780	1	7½(1)	-
Barling:																				
Elkay	Upper Cedar Grove	..do	496	D	2.2	37.7	56.7	5.6	1.0	-	-	-	-	13,900	14,210	1	-	-	-	-
Do	.do	1-1/4-inch by 0	28,586	D	4.5	36.2	55.8	8.0	1.5	-	-	-	-	13,380	14,010	37	2,580	10	7(1) 7½(7) 8(2)	-
Elkay (dock coal)	.do	1-1/4- by 1/4-inch (W)	30,283	D	3.5	37.6	56.4	6.0	1.2	-	-	-	-	13,800	14,300	55	2,760	13	6(1) 7(2) 7½(5) 8(4) 8½(1)	-
Emmett: Island Creek No. 10	.do	Run-of-mine, crushed (W)	519	D	2.7	36.8	56.0	7.2	1.3	-	-	-	-	13,810	14,200	3	-	-	-	-
Kelly:																				
Guyan No. 5	Cedar Grove	6- by 2-inch (W)	6,186	D	1.6	37.2	56.3	6.5	.9	-	-	-	-	14,080	14,310	12	-	-	-	-
Do	.do	1-1/4-inch by 28-mesh (W)	1,141	D	4.1	34.1	58.1	7.8	1.2	-	-	-	-	13,450	14,030	2	-	-	-	-
Do	.do	1- by 1/4-inch (W and OT)	5,750	D	2.7	37.1	57.1	5.8	.9	-	-	-	-	13,800	14,180	23	2,830	8	6(1) 6½(3) 7½(1) 8(1) 8½(1)	-
Do	.do	1-1/4-inch by 0 (W)	6,938	D	4.0	36.4	57.0	6.6	1.2	-	-	-	-	13,680	14,260	30	2,690	9	7(1) 7½(4) 8(2)	-
Guyan No. 5 (dock coal)	.do	1-1/2-inch by 28-mesh (W)	2,398	D	3.8	36.9	57.7	5.4	1.0	-	-	-	-	13,770	14,310	9	2,770	2	7½(2)	-
Do	.do	1-1/4- by 1/4-inch (W)	103	D	1.7	37.3	57.1	5.6	1.2	-	-	-	-	14,190	14,440	1	2,740	1	7½(1)	46
Do	.do	1-1/4-inch by 28-mesh (W and OT)	6,468	D	3.7	37.3	56.6	6.1	1.1	-	-	-	-	13,770	14,310	21	2,790	3	6½(2) 7(1)	-
Lorado:																				
Lorado No. 5 prep. plant	Lower Chilton	1-1/4- by 1/4-inch (W)	4,843	D	4.4	34.9	59.9	5.2	.7	-	-	-	-	13,840	14,470	8	2,830	3	8(3)	-
Do	.do	1-1/4-inch by 28-mesh (W)	1,854	D	5.5	34.0	60.4	5.6	.6	-	-	-	-	13,530	14,320	4	-	-	-	-
Rita:																				
Chafin No. 2	Cedar Grove	5- by 2-inch (W)	90	T	2.5	35.5	57.2	7.3	.7	-	-	-	-	13,630	13,980	1	2,910+	1	-	-
Do	.do	2- by 1-1/4-inch (W)	110	T	2.7	35.8	56.7	7.5	.8	-	-	-	-	13,620	14,000	1	2,910+	1	-	-
Do	.do	1-1/4-inch by 0 (W)	650	T	4.2	35.8	57.4	6.8	1.1	-	-	-	-	13,490	14,080	1	2,720	1	7½(1)	49
Sharples:																				
Boone No. 2-C	Chilton	8- by 5-inch (W)	25	T	2.8	37.1	56.0	6.9	.7	-	-	-	-	13,630	14,020	1	2,460	1	-	-
Do	.do	5- by 3-inch (W)	50	T	3.0	37.7	56.3	6.0	.7	-	-	-	-	13,550	14,280	1	2,910+	1	-	-
Do	.do	3- by 2-inch (W)	50	T	3.3	38.0	56.3	5.7	.8	-	-	-	-	13,800	14,270	1	2,910+	1	-	-
Do	.do	2- by 1-1/4-inch (W)	40	T	3.4	37.8	56.2	6.0	.8	-	-	-	-	13,740	14,220	1	2,910+	1	-	-
Do	.do	1-1/4- by 1/4-inch (W)	260	T	4.6	37.8	56.5	5.7	.8	-	-	-	-	13,550	14,240	1	2,910+	1	-	-
Do	.do	1/4-inch by 0 (W)	60	T	4.9	37.6	56.8	5.6	.8	5.2	79.3	1.6	7.3	13,500	14,200	1	-	-	7(1)	-
Boone No. 2-C (dock coal)	.do	1-1/4- by 1/4-inch (W)	15,099	D	3.8	37.2	56.8	6.0	.7	-	-	-	-	13,630	14,170	35	2,860	10	3½(1) 4½(1) 6½(2) 7(4) 7½(2)	-
Boone No. 5	No. 5 Block	5- by 3-inch (W)	155	T	3.7	37.5	54.2	8.3	.7	5.1	77.4	1.4	7.1	13,250	13,760	1	2,910+	1	-	-
Do	.do	3- by 2-inch (W)	180	T	4.0	37.0	53.8	9.2	.7	-	-	-	-	13,070	13,610	1	2,910+	1	-	41
Do	.do	Modified 2-inch by 0 (10% of 1/4-inch by 0 removed) (W).	900	T	5.4	35.8	55.0	9.2	.7	-	-	-	-	12,820	13,550	1	2,910+	1	-	-
Do	.do	1/4-inch by 0 (W)	100	T	6.4	35.6	54.8	9.6	.8	-	-	-	-	12,600	13,460	1	2,910+	1	6(1)	-
Do	.do	7- by 2-inch (W)	410	D	3.2	35.1	55.2	9.7	.7	-	-	-	-	13,030	13,460	1	-	-	-	-
Do	.do	6- by 2-inch (W)	13,054	D	2.7	36.8	54.9	8.4	.7	-	-	-	-	13,390	13,770	17	-	-	-	-
Do	.do	3- by 2-inch (W)	7,297	D	2.8	36.7	54.8	8.5	.7	-	-	-	-	13,320	13,710	14	-	-	-	-
Do	.do	2- by 1/4-inch (W)	3,247	D	3.5	35.9	56.0	8.1	.8	-	-	-	-	13,270	13,750	6	2,910+	3	5½(1) 6(1) 6½(1)	-
Do	.do	1-1/4- by 1/4-inch (W)	18,436	D	3.7	35.6	55.2	9.2	.7	-	-	-	-	13,020	13,530	23	2,910+	8	4(1) 5½(3) 6(1) 6½(2) 7(1)	-
Do	.do	1-1/4-inch by 10-mesh (W)	7,321	D	5.1	35.5	55.4	9.1	.7	-	-	-	-	12,810	13,500	12	2,910+	1	5½(1)	-

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal 1/	Approximate tons sampled	Kind of sample 2/	Proximate, percent				Ultimate, percent					Calorific value		Number of analyses 3/	Ash-softening temperature, ° F	Number of ash-softening temperatures 3/	Free-swelling index 3/	Hardgrove grindability index 3/
					Moisture, as-received coal	Dry coal														
						Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu, as-received basis	Btu, dry basis					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
WEST VIRGINIA—Continued																				
Logan County--Continued																				
Sharples (Continued):																				
Boone No. 3 (Continued)	No. 5 Block	2-inch by 0 (W)	31,908	D	3.9	35.6	55.2	9.2	.7	-	-	-	-	12,980	13,520	37	2,910+	10	5(1) 5½(5) 6(3)	-
Do.	.do.	1-1/4-inch by 0 (W)	54,046	D	4.8	35.6	55.1	9.3	.7	-	-	-	-	12,840	13,490	63	2,910+	19	6½(1) 3½(1) 5(5)	-
Boone No. 3 (dock coal)	.do.	..do.	24,023	D	4.8	36.3	55.7	8.0	.8	-	-	-	-	13,080	13,750	26	2,910+	6	5½(5) 6(8) 5(1) 5½(2)	-
Stirrat: Omar	Upper and Lower Cedar Grove.	1-1/4- by 1/4-inch (W)	6,541	D	2.6	36.9	57.6	5.5	.9	-	-	-	-	14,000	14,370	17	2,770	6	6(1) 6½(2) 7½(3) 8(3)	-
Stowe:																				
Guyan No. 4	Cedar Grove	6- by 2-inch (W)	208	D	1.8	36.4	56.8	6.8	.7	-	-	-	-	14,060	14,320	2	-	-	-	-
Do.	.do.	1-1/2- by 1/4-inch (W)	1,979	D	2.2	36.7	57.4	5.9	1.1	-	-	-	-	14,090	14,400	3	-	-	-	-
Do.	.do.	1-1/4- by 1/4-inch (W)	7,745	D	2.1	36.5	57.7	5.8	1.0	-	-	-	-	14,110	14,410	11	2,760	5	7½(1)	-
Guyan No. 4 (dock coal)	.do.	1-1/2-inch by 28-mesh (W)	136	D	2.5	37.2	56.2	6.6	1.1	-	-	-	-	13,850	14,200	1	-	-	-	-
Verdunville:																				
National Coal No. 28	Eagle	1-1/2-inch by 0 (W)	260	D	3.9	35.9	60.0	4.1	.7	-	-	-	-	13,930	14,500	1	2,840	1	7(1)	-
McDowell County																				
Iaeger:																				
Iaeger Pocahontas Tipple	Gilbert and Ben Creek.	4-inch lump	15	T	2.3	24.5	68.1	7.4	.7	-	-	-	-	14,110	14,440	1	2,910+	1	-	88
Do.	.do.	4- by 1-1/4-inch	40	T	2.2	25.1	66.2	8.7	1.1	-	-	-	-	13,870	14,180	1	2,890	1	-	-
Do.	.do.	1-1/4-inch by 0	220	T	3.5	24.6	61.3	14.1	1.0	-	-	-	-	12,830	13,300	1	2,780	1	8½(1)	-
Pauley prep. plant	Douglas (Red Ash)	5-inch lump	35	T	1.6	28.8	68.3	2.9	.7	-	-	-	-	14,930	15,170	1	2,560	1	-	80
Do.	.do.	5- by 1-1/4-inch, crushed to 1-1/4-inch (W).	70	T	2.1	28.2	68.9	2.9	.8	-	-	-	-	14,890	15,210	1	2,400	1	-	-
Do.	.do.	1-1/4- by 3/8-inch (W)	85	T	3.8	29.0	67.8	3.2	.9	-	-	-	-	14,550	15,120	1	2,520	1	-	-
Do.	.do.	3/8-inch by 0	220	T	6.0	27.3	65.6	7.1	1.0	-	-	-	-	13,620	14,490	1	2,560	1	8½(1)	-
Superior:																				
Pocahontas Nos. 3 and 4	Pocahontas Nos. 3 and 4.	Run-of-mine, crushed to 3-inch (7- by 1/4-inch (W)).	580	T	6.6	16.3	78.3	5.4	.7	-	-	-	-	13,920	14,900	1	2,520	1	-	-
Do.	.do.	7- by 1-1/4-inch (W)	60	T	3.1	16.1	79.1	4.8	.6	-	-	-	-	14,520	14,980	1	2,410	1	-	91
Do.	.do.	1-1/4- by 1/4-inch (W)	120	T	4.1	15.8	77.9	6.3	.6	-	-	-	-	14,090	14,690	1	2,730	1	5½(1)	-
Marion County																				
Four States:																				
O'Donnell No. 1	Pittsburgh	5- by 2-inch (W)	1,703	D	1.8	41.0	51.5	7.5	2.5	-	-	-	-	13,700	13,950	8	-	-	-	-
Do.	.do.	3- by 1-1/4-inch (W)	257	D	1.8	40.8	51.8	7.4	2.6	-	-	-	-	13,700	13,950	3	-	-	-	-
Do.	.do.	1-1/4- by 1/4-inch (W)	22,985	D	2.1	40.8	52.2	7.0	2.5	-	-	-	-	13,720	14,020	59	2,130	19	7(1) 7½(3) 8(1)	-
Rachel: Joanne (dock coal)	.do.	1-1/4- by 3/4-inch (W)	2,017	D	1.7	39.9	52.6	7.4	2.4	-	-	-	-	13,700	13,930	4	2,240	2	8½(3) 7(1) 8½(1)	-
Mingo County																				
Delbarton: Adanac Tipple	Upper Cedar Grove	Run-of-mine, crushed to 1-1/4-inch	180	T	2.5	36.2	51.3	12.5	1.5	-	-	-	-	12,820	13,150	1	2,700	1	6(1)	44

Kermit:																				
Burning Creek	No. 2 Gas	1- by 1/4-inch (Run-of-mine, crushed to 1-inch) (W and OT).	180	T	4.5	41.8	52.6	5.6	1.1	-	-	-	-	13,510	14,160	1	2,820	1	-	-
Do	.do	1/4-inch by 0	110	T	4.6	38.8	55.3	5.9	1.5	-	-	-	-	13,380	14,020	1	2,270	1	6(1)	46
Davis No. 1	.do	Run-of-mine, crushed to 2-inch	200	T	3.0	38.1	54.6	7.3	1.0	5.1	77.6	1.5	7.5	13,430	13,850	1	2,660	1	6(1)	42
Lobata: Lobata Tipple	Alma	..do	215	T	2.5	37.2	56.8	6.0	.6	-	-	-	-	14,030	14,400	1	2,910+	1	7½(1)	-
Matewan:																				
Belfry Tipple	.do	Run-of-mine, crushed to 1-1/4-inch	280	T	3.5	35.8	54.9	9.3	.7	-	-	-	-	13,240	13,720	1	2,910+	1	7½(1)	44
Cook Alma Tipple	Cedar Grove	Run-of-mine, crushed to 2-inch	205	T	2.4	37.2	52.8	10.0	1.4	-	-	-	-	13,230	13,560	1	2,700	1	6½(1)	45
Dasmar Tipple	Alma	..do	250	T	3.2	36.3	58.8	4.9	.6	-	-	-	-	14,120	14,570	1	2,910+	1	7½(1)	-
Ragland:																				
Island Creek No. 24	Lower Cedar Grove	5- by 3-inch (W)	5,161	D	2.1	36.9	58.4	4.7	.6	-	-	-	-	14,190	14,450	6	-	-	-	-
Do	.do	3- by 2-inch (W)	8,772	D	2.3	36.8	58.1	5.1	.5	-	-	-	-	14,110	14,440	9	2,840	1	7½(1)	-
Do	.do	1/4-inch by 0 (W)	2,114	D	4.2	35.5	56.6	7.9	.8	-	-	-	-	13,360	13,940	4	2,820	2	8(2)	-
National Coal No. 25	.do	3- by 2-inch (W)	19,150	D	2.5	36.9	59.8	3.3	.5	-	-	-	-	14,420	14,790	32	-	-	-	-
Do	.do	1-1/2-inch by 0 (W)	2,605	D	4.5	36.3	59.8	3.9	.7	-	-	-	-	14,050	14,710	4	2,580	3	8(1)	-
Rawl: Rawl Tipple	Alma	Run-of-mine, crushed to 2-inch	305	T	3.0	36.6	58.8	4.6	.6	-	-	-	-	14,150	14,590	1	2,780	1	7½(1)	46
Red Jacket:																				
Island Creek No. 34	Upper Cedar Grove	Run-of-mine, crushed (W)	76,200	D	3.1	37.3	56.2	6.5	1.3	-	-	-	-	13,800	14,240	94	2,820	23	5½(1) 6(2) 6½(3) 7(5) 7½(10) 8(2)	-
Do	.do	1/4-inch by 0 (W)	19,750	D	4.9	35.3	55.9	8.8	1.6	-	-	-	-	13,140	13,810	21	2,500	6	5(1) 7½(1) 8(3) 8½(1)	-
Monongalia County																				
Morgantown:																				
Arkwright No. 1	Pittsburgh	1-1/4- by 1/4-inch (W)	12,571	D	1.4	39.6	53.1	7.3	2.4	-	-	-	-	13,890	14,090	20	2,230	6	7(1) 7½(1) 8(4)	-
Christopher No. 5	Sewickley	..do	15,504	D	1.5	38.9	50.4	10.7	3.1	-	-	-	-	13,280	13,490	19	2,490	7	7(1) 7½(1) 8(3) 8½(2)	-
Do	.do	1-1/2-inch by 0 (W and AC)	140	D	2.1	39.8	49.3	10.8	3.4	-	-	-	-	13,190	13,480	2	-	-	-	-
Nicholas County																				
Belva (Fayette County):																				
Conley	Coalburg	Run-of-mine, crushed to 1-1/4-inch	250	T	2.6	35.1	53.8	11.1	.8	-	-	-	-	13,060	13,410	1	2,910+	1	7(1)	43
Craigsville:																				
Radar (Panther No. 5)	Sewell	1-inch by 0	513	D	3.3	29.4	66.4	4.2	.5	-	-	-	-	14,210	14,700	1	2,570	1	7½(1)	-
Drennen:																				
Clearfield Eagle	Peerless	Run-of-mine	100	T	2.4	34.3	57.2	8.5	1.1	5.1	78.0	1.4	5.9	13,660	14,000	1	2,590	1	8½(1)	52
Golden Eagle	Big Eagle	..do	120	T	3.0	32.9	59.9	7.2	.7	5.0	79.6	1.6	5.9	13,840	14,270	1	2,910+	1	8½(1)	54
Radar Eagle No. 2	.do	..do	150	T	3.4	32.6	61.4	6.0	.7	5.0	81.1	1.6	5.6	13,840	14,330	1	2,910+	1	8½(1)	55
Summersville: Peerless No. 7	Peerless	Run-of-mine, crushed to 3-inch	850	T	2.6	33.8	56.4	9.8	1.1	5.0	76.7	1.5	5.9	13,300	13,650	1	2,280	1	8½(1)	54
Preston County																				
Kingwood: Mary Sara	Upper Freeport	Run-of-mine, crushed to 1-1/4-inch (W and AC).	995	T	3.1	31.4	59.3	9.3	1.9	-	-	-	-	13,650	14,090	1	2,510	1	8½(1)	78
Raleigh County																				
Prince (Fayette County):																				
Royal Tipple	Fire Creek	Run-of-mine, crushed to 1-1/2-inch (5- by 1/2-inch (W)).	450	T	5.1	19.3	73.9	6.8	.8	-	-	-	-	13,790	14,530	1	2,790	1	9(1)	99
Upshur County																				
Adrian: Adrian	Upper Freeport	Run-of-mine, crushed to 2-inch (W)	150	T	2.7	37.8	51.6	10.6	1.5	5.2	75.7	1.4	5.6	13,250	13,620	1	2,480	1	8(1)	55
Buckhannon:																				
Scott No. 4 Tipple	Redstone	Run-of-mine, crushed to 1-1/2-inch	150	T	2.5	39.8	54.0	6.2	2.5	-	-	-	-	13,790	14,140	1	2,080	1	7½(1)	55

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.

TABLE 1. - Analyses of tipple and delivered samples during the fiscal year 1966—Continued

State, county, town, and mine	Bed	Size of coal[3]	Approximate tons sampled	Kind of sample	Proximate, percent: Moisture, as-received coal	Proximate, percent: Dry coal: Volatile matter	Proximate, percent: Dry coal: Fixed carbon	Proximate, percent: Dry coal: Ash	Ultimate, percent: Dry coal: Sulfur	Ultimate, percent: Dry coal: Hydrogen	Ultimate, percent: Dry coal: Carbon	Ultimate, percent: Dry coal: Nitrogen	Ultimate, percent: Dry coal: Oxygen	Calorific value: Btu, as-received basis	Calorific value: Btu, dry basis	Number of analyses	Ash-softening temperature, ° F	Number of ash-softening temperatures	Free-swelling index	Hardgrove grindability index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
WEST VIRGINIA—Continued																				
Wyoming County																				
Bolt (Raleigh County): Bolt		Run-of-mine, crushed	30,888	D	4.8	30.2	63.8	6.0	1.2	-	-	-	-	13,950	14,620	34	2,680	9	5(2) 5½(4) 6(1) 7(1)	-
Coal Mountain:																				
Coal Mountain No. 9-B	Powellton	1-1/4- by 1/4-inch (W)	842	D	3.0	34.5	62.1	3.4	.6	-	-	-	-	14,410	14,850	15	2,910+	3	7(1) 8(1) 8½(1)	-
Do	.do	3/4-inch by 0	31,086	D	3.5	34.2	61.8	4.0	.6	-	-	-	-	14,260	14,780	33	2,880	6	7(2) 7½(2) 8(1) 8½(1)	-
Do	.do	1/4-inch by 0	2,569	D	5.2	30.9	57.2	11.9	.6	-	-	-	-	12,800	13,500	3	-	-	-	-
Coal Mountain No. 12	Dorothy	1-1/4- by 1/4-inch (W)	5,069	D	1.9	35.2	59.6	5.2	.6	-	-	-	-	14,290	14,580	8	2,910+	2	7½(1)	-
Do	.do	2-inch by 0	4,865	D	3.7	34.3	59.3	6.4	.6	-	-	-	-	13,850	14,380	8	2,910+	1	7½(1)	-
Do	.do	1-1/2-inch by 0	33,725	D	2.9	34.2	59.5	6.3	.6	-	-	-	-	13,980	14,410	47	2,910+	10	8(1) 8½(1)	-
Do	.do	1-1/4-inch by 0	40,664	D	3.7	33.9	59.5	6.6	.6	-	-	-	-	13,820	14,360	56	2,900	14	6½(1) 7(3) 7½(4) 8(4) 8½(1)	-
Kopperston:																				
Kopperston No. 2 (dock coal)	No. 2 Gas	1-1/2-inch by 0 (W)	7,880	D	3.2	31.3	64.1	4.6	.7	-	-	-	-	14,320	14,790	8	2,910+	3	7½(2) 8(1)	-
WYOMING																				
Carbon County																				
Hanna:																				
Hanna		10- by 2-1/2-inch	175	T	13.0	42.2	52.9	4.9	.8	-	-	-	-	11,140	12,810	1	2,200	1	-	-
Do		2-1/2- by 1-1/2-inch	260	T	13.4	42.4	51.2	6.4	.9	-	-	-	-	10,870	12,550	1	2,150	1	-	-
Do		1-1/2- by 3/8-inch	630	T	13.9	41.3	52.2	6.5	.9	-	-	-	-	10,810	12,560	1	2,100	1	-	52
Do		3/8-inch by 0	700	T	14.6	41.2	52.2	6.6	1.0	-	-	-	-	10,650	12,470	1	2,100	1	-	-
Lincoln County																				
Kemmerer:																				
Elkol	Adaville	1-inch by 0	9,223	D	20.2	42.7	54.5	2.8	.7	-	-	-	-	10,310	12,920	11	-	-	-	-
Sorensen		Run-of-mine, crushed to 1-3/8-inch	1,000	T	28.6	43.9	50.8	5.3	.3	-	-	-	-	8,020	11,230	1	2,230	1	-	84
Sheridan County																				
Sheridan:																				
Big Horn	Monarch	1-1/4- by 1/4-inch	10,468	D	21.6	43.5	51.1	5.4	.6	-	-	-	-	9,850	12,560	32	2,170	9	-	-
Do	.do	1-1/2-inch by 0	5,284	D	22.6	42.4	52.2	5.4	.5	-	-	-	-	9,590	12,390	13	2,210	4	-	-
Sweetwater County																				
Rock Springs:																				
Rainbow		5-inch lump	40	T	9.9	42.9	55.3	1.8	.8	5.4	78.2	1.8	12.0	12,440	13,810	1	2,250	1	-	-
Do		5- by 3-inch	30	T	10.0	42.8	55.2	2.0	.7	-	-	-	-	12,420	13,800	1	2,270	1	-	-

Do.		1-5/8- by 1-1/4-inch (AC) (3- by 1-5/8-inch, crushed to 1-5/8-inch).	25	T	9.9	42.5	55.0	2.2	.8	-	-	-	-	12,420	13,790	1	2,210	1	-	50
Do.		1-1/4- by 3/16-inch (AC and OT)	160	T	10.3	43.1	54.1	2.8	.8	-	-	-	-	12,210	13,610	1	2,210	1	-	-
Do.		3/16-inch by 0	65	T	11.9	42.1	52.7	5.2	1.2	-	-	-	-	11,750	13,340	1	2,140	1	1(1)	-
									ALASKA											
Matanuska Field																				
Sutton: Jonesville		2-1/2-inch by 0	291,595	D	8.4	-	-	14.7	-	-	-	-	-	11,120	12,140	311	2,850	16	-	-
Nenana Field																				
Healy Fork:																				
Cripple Creek		Run-of-mine, crushed	152,757	D	22.9	-	-	10.6	-	-	-	-	-	8,620	11,190	162	-	-	-	-
Usibelli		..do.	180,355	D	21.9	-	-	11.8	-	-	-	-	-	8,750	11,210	132	-	-	-	-

1/ See Explanation of Symbols (p. 3).

2/ Numbers above 1 indicate the number of deliveries averaged.

3/ Numbers in parentheses indicate the number of determinations made.